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Journal

of

THE ROYAL AERONAUTICAL SOCIETY

OCTOBER 1955

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FIFTH ANGLO-AMERICAN AERONAUTICAL CONFERENCE

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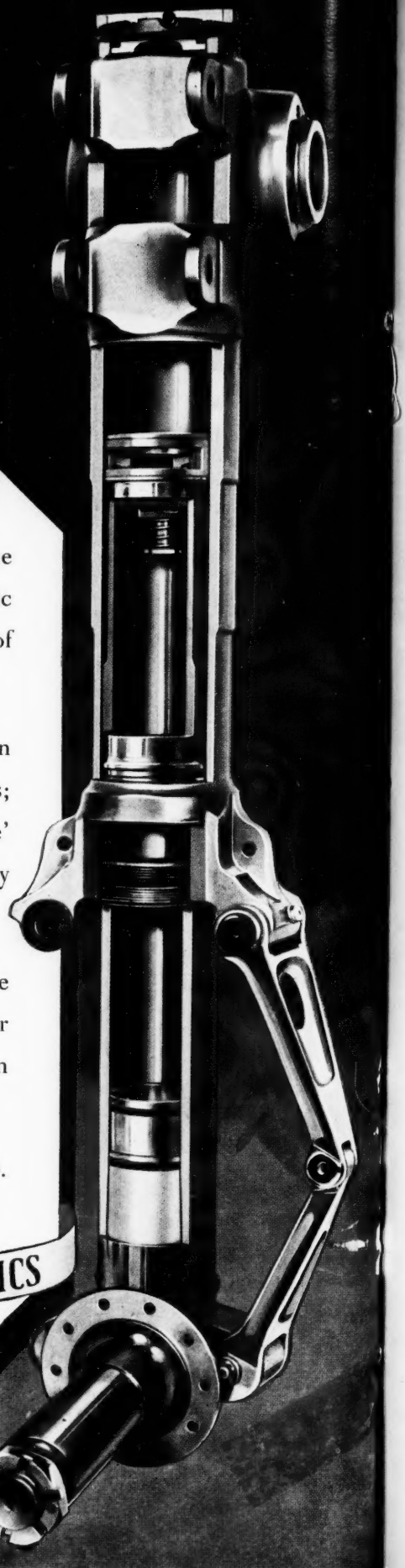

Journal of

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ADDITIONS TO THE LIBRARY. REPORTS.

All communications for publication in, and advertisements for, the JOURNAL *should be addressed to the Editor,* JOAN BRADBROOKE, *A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary,* A. M. BALLANTYNE, *T.D., B.Sc., Ph.D., Hon.F.C.A.I., A.F.I.A.S., A.F.R.Ae.S.*

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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Secretary's News Letter

October 1955.

MANY OF YOU will have heard that Mr. Deryck C. Smith will have left the staff of the Society when these notes are read. He has been invited to join the Secretariat of A.G.A.R.D., and will have taken up his new appointment at the beginning of October 1955.

That he will be missed by the Society, both by the staff and by the members, is something which requires no emphasis; equally true is the fact that with him he carries the good wishes of every member of the Society. Deryck Smith joined the staff in 1945, and during these past ten years he has made a host of friends.

His work has in no small way contributed much to the success of the Branches. During my visits to many Branches I have joked, " If there is anything you think I can do—Smith will do it for you." That there was more than an element of truth in this was realised—and results showed this.

To enumerate all the things Deryck Smith has done for the Society would need much time and space; in the past five years his major achievement has not been in the more administrative functions, but in the more specialised technical department, which under his "loving" care has increased in prestige through achievement.

Many are willing and Smith is one of these. Many members have asked, and they have received of Smith's time and knowledge, and have been grateful.

In one of the earliest News Letters I stressed the fact that I had inherited a good staff from Captain Pritchard. I have never revised that opinion, for I was in the peculiar position of not knowing what I did not know. Deryck Smith helped me gain that knowledge, and he has been of considerable assistance to me personally.

Now someone else has recognised his worth, and I have many thoughts, but no surprise.

I'm sure every member of the Society will join me in wishing him every success with A.G.A.R.D., and say, " I'll be seeing you "—which is a common phrase in the language of many of the natives of the member states of A.G.A.R.D.

With the resignation of Mr. Smith, who was Head of the Technical Department, henceforth Mr. J. A. Dunsby and Mr. A. J. Barrett will share the responsibilities of the technical work, the former becoming Head of the Aerodynamics Group, and the latter Head of the Structures Group of the Technical Department.

A. M. Ballantyne

Secretary

NOTICES

An annual sum of £250 is available for premium awards for papers, including Technical Notes, published in the Journal. Members and non-members of the Society are invited to submit papers on any aspect of aeronautics

Lectures on the Fatigue of Metals

A course of twelve lectures on the Fatigue of Metals has been arranged by the Civil and Mechanical Engineering Department of Northampton Polytechnic, with the assistance of the Society.

These lectures will be given at the Polytechnic on Thursday evenings at 6.45 p.m., starting on 29th September 1955. The London rate of fee for the course is £1, and enrolment may be by personal attendance or by post. The Head of the Department is Mr. J. C. Oakden, M.A., M.I.Mech.E., Northampton Polytechnic, St. John Street, E.C.1.

The Lectures to be given, which are intended for engineers and physicists, of graduate or equivalent standard, are:—

29th September	General and Historical Survey H. L. Cox (National Physical Laboratory)
6th October	Fatigue Testing P. G. Forrest (National Physical Laboratory)
13th October	Metal Physics in Relation to Fatigue Dr. N. Thompson (University of Bristol)
20th October	Metallurgical Aspects of Fatigue P. J. E. Forsyth (Royal Aircraft Establishment, Farnborough)
27th October	The Statistical Aspect of Fatigue Testing Dr. E. W. C. Wilkins (Royal Aeronautical Society)
3rd November	Notches and Stress-raisers N. E. Frost (Mechanical Engineering Research Laboratory, East Kilbride, Glasgow)
10th November	Effects of Surface Finish and Surface Treatment E. R. Gadd (Bristol Aeroplane Company)
17th November	Stress History and Cumulative Damage J. C. Levy (Northampton Polytechnic)
24th November	Corrosion Fatigue R. B. Waterhouse (Department of Colloid Science, University of Cambridge)
1st December	Fatigue Loads and Their Effect on Aircraft Structures J. Taylor (Royal Aircraft Establishment, Farnborough)
8th December	Fatigue in Aircraft Structures D. C. Smith (A.G.A.R.D.)
15th December	Design of Structures in Relation to Fatigue Failure H. L. Cox (National Physical Laboratory)

Graduates' and Students' Section Dance

All Graduates and Students have been sent a leaflet giving them particulars of the Annual Dance to be held on Friday 28th October 1955 at 4 Hamilton Place, London, W.1, from 8 p.m. to 11.30 p.m. Tickets are 7s. 6d. single or 15s. double and the price is inclusive of refreshments. Application for tickets should be made to E. J. Catchpole, 12 Amery Road, Harrow, Middlesex.

Baden-Powell Prize

The Baden-Powell Prize has been awarded to H. F. C. Newby who was considered to be the best student in the June 1955 Associate Fellowship Examination.

Scholarships and Grants

The Council have pleasure in announcing that the following Scholarships and Grants have been awarded:

Royal Aeronautical Society's Charter Scholarship 1955/56—Thomas Johnson Black.

Edward Busk Studentship in Aeronautics 1955/56—James Ian Dodds.

Geoffrey de Havilland Memorial Scholarship 1955/56—Ernest Angus Boyd.

Grants in aid of further study and research in aeronautics have been awarded to the following:—

Michael Geoffrey Bader
Edgar Allinson Bunt
Edward Michael Cowburn
Michael A. P. Wilmer

Royal Aeronautical Society University Prizes in Aeronautics 1955

The following Students have been awarded Royal Aeronautical Society Prizes in Aeronautics for 1955:—

P. A. Knowles and P. Talbot—University of Southampton.
C. W. Skingle—Queen Mary College, University of London.
O. P. Nicholas and R. R. Philpot—University of Bristol.
Thomas Adam—University of Glasgow.

E. J. N. Archbold Memorial Prize 1954

The E. J. N. Archbold Memorial Prize for 1954 has been awarded jointly to:—

W. J. D. Brooks and E. J. John.

News of Members

John Barker (*Associate Fellow*) has taken up a post as Chief Draughtsman at the London Office of the Bristol Aeroplane Co. Ltd.

C. E. Barkworth (*Associate*) has relinquished his appointment as General Manager of Canadian Chain Belt Ltd. and is now President of Crothers Manufacturing Ltd., of Toronto.

R. A. Clark (*Associate*) now holds the post of Chief Inspector, Engine Division, Blackburn and General Aircraft Ltd.

J. G. Dawson (*Associate Fellow*), formerly Chief Engineer of the Shell Organisation's Thornton Research Centre, has joined F. Perkins Ltd., of Peterborough, as Manager of the Experimental Department.

E. Dymond (*Associate Fellow*) has recently taken up an appointment with Sangamo Generators in Illinois, U.S.A.

H. T. Ellingworth (*Associate Fellow*) has been appointed Assistant Director, Air Technical Publications, Ministry of Supply, Chessington.

P. Fielding (*Associate Fellow*), formerly Special Projects Engineer to Saunders-Roe Ltd., is shortly to join the Special Projects Division of the Lockheed Aircraft Corporation, Georgia, U.S.A.

Wing Commander R. Fordham (*Associate Fellow*) has been appointed to serve with the Royal Danish Air Force at the Headquarters at Vedbaek, Denmark.

D. J. Foster (*Graduate*) has been appointed an Engineering Aerodynamicist with Avro Aircraft Ltd., Toronto.

G. H. Fuller (*Associate*) was recently appointed Quality Engineer in charge of the Central Investigation Department of Tilling-Stevens Ltd.

A. H. C. GREENWOOD (*Associate*) has been appointed a Special Director of Vickers-Armstrongs (Aircraft) Ltd.

A. GRIFFITHS (*Associate Fellow*) has changed his employment to Assistant Lecturer at the Constantine Technical College, Middlesborough.

E. T. JONES (*Fellow*) has been appointed Director General of Technical Development (Air) in succession to Mr. G. W. H. Gardner, who is to become Director of the Royal Aircraft Establishment, Farnborough, on 1st November.

GROUP CAPTAIN A. C. KERMODE (*Fellow*) has been appointed Director of Educational Services, Royal Air Force, with the acting rank of Air Vice-Marshal. He will take up his new post in late November.

J. MONTANARO (*Associate Fellow*) has left the Ministry of Supply and has taken up an appointment with the National Research Council of Canada in the Division of Mechanical Engineering, in connection particularly with helicopter de-icing problems.

K. W. WATKINS (*Graduate*) has been appointed Project Engineer by the Hymatic Engineering Co. Ltd., Redditch Worcs.

Diary

LONDON

6th **October**

MAIN LECTURE.—British Commonwealth and Empire Lecture. The Growth of Aeronautical Research in Canada during the Post-War Decade. Dr. J. J. Green, M.B.E. Royal Institution, 21 Albemarle St., London, W.1. 6 p.m. (Tea 5.30 p.m.).

12th October

GRADUATES' AND STUDENTS' SECTION.—Visit to National Aeronautical Establishment, Bedford. *See* Notice.

19th October

GRADUATES' AND STUDENTS' SECTION.—Films (Including "High Altitude Research" (experiments with the Aerobee rocket), "Faster than Sound" (Vickers' transonic research rockets), "The Crescent Wing" (Handley Page development) and films showing the Fairey "Stooge" research vehicle and delta-wing high-angle launch project). The Library, 4 Hamilton Place, London, W.1. 7.30 p.m.

20th October

MAIN LECTURE.—The Jet Flap. I. M. Davidson. Royal Institution, 21 Albemarle Street, London, W.1. 6 p.m. (Tea 5.30 p.m.).

25th October

SECTION LECTURE.—Boundary Layer Effects in Supersonic Flow. R. J. Monaghan. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

28th October

GRADUATES' AND STUDENTS' SECTION.—Dance. The Library, 4 Hamilton Place, London, W.1. 8-11.30 p.m. (*See Notice*).

8th **November**

SECTION LECTURE.—High Aspect Ratio Wings. M. Hurel. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

10th November

MAIN LECTURE AT MERTHYR TYDFIL BRANCH.—Combustion. Dr. J. S. Clarke, O.B.E. Teddington Restaurant, Teddington Aircraft Controls, Cefn Coed, Merthyr Tydfil. 7 p.m.

15th November

SECTION LECTURE.—The Planning of Experiments. Sir Ronald A. Fisher. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

17th November

ALL DAY SECTION LECTURE ON AIRCRAFT DESIGN PHILOSOPHY.—Structural Testing: Dr. P. B. Walker, C.B.E. Fatigue; H. Giddings. Flight Loads: C. F. Joy. Safety Factors: J. K. Williams. Institution of Civil Engineers, Gt. George Street, London, S.W.1. 10 a.m.

GRADUATES' AND STUDENTS' SECTION.—The Supersonic Fighter. J. W. Fozard. The Library, 4 Hamilton Place, London, W.1. 7.30 p.m.

19th November

GRADUATES' AND STUDENTS' SECTION.—Visit to London Airport.

22nd November

SECTION LECTURE.—Aviation Journalism. Charles Gardner, O.B.E., The Library, 4 Hamilton Place, London, W.1. 7 p.m.

29th November

SECTION LECTURE.—The Noise of Jet Engines. F. B. Greatrex. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

1st **December**

MAIN LECTURE AT BOSCOMBE DOWN BRANCH.—Free Flight Techniques for High Speed Aerodynamic Research. P. A. Hufton. Main Dining Hall, Airmen's Mess, A. & A.E.E., Boscombe Down. 6.30 p.m. (Tea 5.30 p.m.).

GRADUATES' AND STUDENTS' SECTION.—Aeroelasticity in Practice. H. S. Liner. The Library, 4 Hamilton Place, London, W.1. 7.30 p.m.

6th December

SECTION LECTURE.—Fatigue Aspects of Structural Design. W. A. P. Fisher. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

14th December

GRADUATES' AND STUDENTS' SECTION.—The Domain of the Helicopter. R. Hafner. The Library, 4 Hamilton Place, London, W.1. 7.30 p.m.

16th December

SECTION LECTURE.—Lecture on Airships. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

20th December

SECTION LECTURE.—Recent Advances in Aircraft Adhesives. Dr. N. A. de Bruyne. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

5th January 1956

YOUNG PEOPLE'S LECTURE.—Test Flying—Current Problems and Techniques. Wing Cdr. R. P. Beamont, O.B.E., D.S.O., D.F.C. The Institution of Civil Engineers, Gt. George Street, London, S.W.1. **3 p.m.** (Tea 4.30 p.m.)

BRANCHES

5th **October**

Brough.—Anglo-American Conference. The President, N. E. Rowe, Electricity Showrooms, Hull. 7.30 p.m.

6th October

Isle of Wight.—Recent Developments in Production Processes. W. E. Goff. The Clubhouse, Saunders-Roe Sports and Social Club, Church Walk, E. Cowes. 6.30 p.m.

Yeovil.—The Future of Air Power. Air Marshal Sir Robert Saundby, K.B.E., C.B. Park School, Park Road (off Princes Street), Yeovil. 7.30 p.m.

12th October

Chester.—An American Outlook on Turbo-Prop Aircraft. L. H. Caldwell. Grosvenor Hotel, Chester. 7.30 p.m.

Halton.—The Propeller Gas Turbine Engine. A. C. Clinton. Branch Hut, R.A.F., Halton. 6.45 p.m.

Manchester.—Development of the Guided Weapons. W. H. Stevens. Reynolds Hall, College of Technology, Manchester. 7.30 p.m.

17th October

Halton.—Film and Talk: Overseas Visit to Branches. Dr. A. M. Ballantyne. Branch Hut, R.A.F., Halton. 6.45 p.m.

19th October

Coventry.—Cabin Hoods. Dr. A. Holland. The Wine Lodge, Coventry. 7.30 p.m.

Reading and District.—Air-to-Air Photography: Lecture and Film Show. Russell Adams. The Canteen, Western Manufacturing (Reading) Ltd., The Aerodrome, Woodley. 6 p.m.

20th October

Isle of Wight.—The Domain of the Helicopter. R. Hafner. The Clubhouse, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6.30 p.m.

Southampton.—Gas Turbines: Basic Principles and Production Problems. C. E. Wurr. The Polygon Hotel, Southampton. 7.15 p.m.

27th October

Yeovil.—Anglo-American Aeronautical Conference 1955. E. W. Still. Park School, Park Road (off Princes Street), Yeovil. 7.30 p.m.

31st October

Halton.—Problems of Space Flight. Flt.-Lieut. R. W. Durrant. Branch Hut, R.A.F., Halton. 6.45 p.m.

1st **November**

Boscombe Down.—Aircraft Engineering and Operations in the Arctic. Major J. H. Webb, U.S.A.F. Main Dining Hall, Airmen's Mess, A. & A.E.E., Boscombe Down. 5.30 p.m.

2nd November

Southampton.—Flight Refuelling. P. S. McGregor, Institute of Education, Southampton University. 7 p.m.

3rd November

Isle of Wight.—Annual Dinner. Hotel Ryde Castle.

7th November

Glasgow.—Earth Satellites. M. W. Ovenden. Royal Technical College. 7.15 p.m.

Halton.—Films. Branch Hut, R.A.F., Halton. 6.45 p.m.

9th November

Chester.—Design Features of the Dart Engine. R. J. Shire. Grosvenor Hotel, Chester. 7.30 p.m.

10th November

Brough.—Second Sir George Cayley Memorial Lecture: The End of an Epoch in Air Warfare. Marshal of the R.A.F. Sir John Slessor. Station Hotel, Hull. 7.30 p.m.

14th November

Halton.—Airframe Fatigue. W. Tye, O.B.E. Branch Hut, R.A.F., Halton. 6.45 p.m.

16th November

Coventry.—Lecture by H. F. Rainbow. The Wine Lodge, Coventry. 7.30 p.m.

Manchester.—Interplanetary Flight. E. Burgess. Reynolds Hall, College of Technology, Manchester. 7.30 p.m.

Reading and District.—Man and the Aircraft Workspace. Wing Cdr. H. P. Ruffell Smith. The Canteen, Western Manufacturing (Reading) Ltd., The Aerodrome, Woodley. 6 p.m.

21st November

Halton.—Photographing Aircraft. Charles E. Brown. Branch Hut, R.A.F., Halton. 6.45 p.m.

24th November

Isle of Wight.—Ejection from High Speed Aircraft. J. Martin, O.B.E. The Clubhouse, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6.30 p.m.

28th November

Halton.—Film: "Target for Tonight." Branch Hut, R.A.F., Halton. 6.45 p.m.

2nd **December**

Chester.—Annual Dance. Four-Ways Restaurant, Chester.

5th December

Halton.—Parachutes. W. D. Brown. Branch Hut, R.A.F., Halton. 6.45 p.m.

7th December

Brough.—Aerial Photography. Charles E. Brown. Electricity Showrooms, Hull. 7.30 p.m.

Chester.—The Pioneer. N. J. Capper. Grosvenor Hotel, Chester. 7.30 p.m.

Reading and District.—Airframe Fatigue. W. Tye, O.B.E. The Canteen, Western Manufacturing (Reading) Ltd., The Aerodrome, Woodley. 6 p.m.

8th December

Isle of Wight.—Annual General Meeting and Film Show. The Clubhouse, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6.30 p.m.

9th December

Glasgow.—Test Flying. Ben Gunn. Rolls-Royce, Hillington. 7.15 p.m.

12th December

Halton.—Film: "The First of the Few." Branch Hut, R.A.F., Halton. 6.45 p.m.

14th December

Coventry.—Film: "We Saw it Happen." United Aircraft Export Corp. film of the first 50 years of flying. The Wine Lodge, Coventry. 7.30 p.m.

Manchester.—N.A.T.O. Air Power and the Preservation of Peace. Air Marshal Sir Robert Saundby, K.B.E., C.B. Reynolds Hall, College of Technology, Manchester. 7.30 p.m.

19th December

Halton.—Space Flight. J. Humphries. Branch Hut, R.A.F., Halton. 6.45.

Elections

The following is a list of new members and transfers of membership of the Society:—

Associate Fellow

Leslie Maurice Carlile (*from Graduate*)
Roy Gaston Fowler
Lancelot John Hope (*from Graduate*)
Harry Lomas (*from Graduate*)
Arthur Summers

Graduates

Vijaisingh Fathesingh Angre
Leslie Arthur Hall (*from Student*)
Harold Clive Jamieson
Dhanvada Madhava Rao (*from Student*)
Edmund John Smith
John Derek Watkins (*from Student*)

Students

Arthur Stuart Blears
John Leslie Hatton
Stephen Anthony Outhwaite
Ranga Rao Raghavendra Rao
Denis Vivian Warren
Joseph Bernard Young

Graduates' and Students' Section—Visits

A visit has been arranged to the National Aeronautical Establishment at Bedford for Wednesday 12th October. Application should be made to Mr. P. D. Stewart, B.O.A.C. Operations Development Unit, London Airport, Hounslow, Middlesex.

A visit has also been arranged to London Airport on Saturday 19th November. Among the arrangements for this visit are a tour of the British European Airways Engineering Base and representative aircraft, M.T.C.A. Central Area and the new Passenger Building. Applications for this visit should be made to N. K. Benson, 14 Wakering Road, Barking, Essex.

The Journal

For the past few months all members have been receiving their Journals rolled and wrapped and only a few adverse comments have been received. Plans for the Journal in 1956 are now being made and the Editor would be glad to know if members are satisfied with the wrappers or, if they would prefer their Journals in envelopes again.

The Journal of the Royal Aeronautical Society

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

VOLUME 59 OCTOBER 1955 NUMBER 538

Aeronautical Research in Sweden

by

Bo K. O. LUNDBERG, F.R.Ae.S., F.I.A.S.

(*Director of The Aeronautical Research Institute of Sweden*)

The 953rd Lecture to be given before the Royal Aeronautical Society was held at the Institution of Mechanical Engineers, Birdcage Walk, London, S.W.1, on 21st April 1955, and was presided over by SIR SYDNEY CAMM, C.B.E., F.R.Ae.S., President of the Society. Introducing the Lecturer, BO. K. O. LUNDBERG, the President said that Mr. Lundberg had had a varied and distinguished career. He was a Fellow of both the Royal Aeronautical Society and the Institute of the Aeronautical Sciences and gave the 18th Wright Brothers' Lecture in America in December 1954. He received his flight training in 1926 in the Royal Swedish Air Force and graduated from Sweden's Royal Institute of Technology in 1931, joining the Aeroplane Division of the Swedish Railway Works as Chief of Aerodynamics and Structures, and also as test pilot. In 1935 he became Test Pilot and Chief of the Department of Calculations for E. Sparmann's Aeroplane Works. In 1937 and 1938 he was Assistant Chief Inspector, Royal Board of Civil Aviation and the following year was Chief of the Aircraft Division of A. B. Götaverken. In 1940 he was a member of the Royal Swedish Air Force Commission in the United States, and when Sweden decided to develop its own aviation industry and make its own aeroplanes, Mr. Lundberg, as Chief Designer, organised the Royal Swedish Air Force plant in Stockholm and was responsible for the design of the J-22 fighter which went into quantity production six months before the prototype made its first flight and went into service with the Royal Swedish Air Force with no major modifications. In 1943 Mr. Lundberg was made Chief of the Design Office of the Royal Swedish Air Force's Aircraft Board and in the following year became Chief of the Structures Department of the Aeronautical Research Institute of Sweden. In 1948 he was appointed to his present position of Director of that Institution.

1. Introduction

I wish first to express my deep appreciation for having been invited by the Council of the Royal Aeronautical Society to present a lecture on aeronautical research in Sweden. As the subject is a very broad one, it was necessary for me to consider rather thoroughly what would be expected from this paper and thus, which limitations in its scope should preferably be made.

Before the 1939-45 War it was possible to design new, successful aeroplanes mainly on the basis of experience from previous types in combination with generally available design information, such as aerofoil data. The success was, in fact, often more dependent on the skill of the designer than on the amount of research and detailed aerodynamic and structural testing done. After the advent of jet propulsion and transonic and supersonic speeds this situation changed radically. Nowadays a substantial amount of basic and applied research, as well as scientifically performed development work, is a necessity for any country, regardless of size, attempting to produce its own designs of efficient and safe aircraft. This applies to Sweden, and although our research capacity in aeronautics is much smaller than in many other countries, it would be an impossible task to present even a nearly complete account of our aeronautical research within the limits of a lecture of reasonable length.

In the first place it is natural for me to deal with those main branches of aeronautical research in Sweden which constitute the activities of the Aeronautical Research Institute of Sweden—the F.F.A. (Flygtekniska försöksanstalten)—namely aerodynamics and structures, and to give accounts of these activities both within and outside the F.F.A. This implies that not only engine research but also such increasingly important fields of research as electronics, metallurgy, fuels, aero medicine, and so on, are excluded from this paper. However, some information will be given about the work at the F.F.A. in the field of measurement techniques relevant to experimental research in aeronautics.

Even with the said limitations, it was found necessary to make a choice as to whether the paper should mainly consider such general questions as the organisation, capacity and costs of our aeronautical research, or whether the paper should be confined mostly to descriptions of wind tunnels and other equipment and to accounts of some interesting items of research.

The author feels that some timely or otherwise interesting research results, together with a limited amount of technical data as regards the more important pieces of equipment, would be more interesting than a lot of detailed information about organisation, personnel and costs. An additional reason for devoting

FIGURE 1. Dr. Enoch Thulin (1881-1919), pioneer of Swedish aviation and aeronautical research.

most of the space to the results of research is the fact that a paper dealing with the financial background and organisation of aeronautical research and development in Sweden has been published quite recently[1].

Although the main part of this paper will thus deal with the technical side of aeronautical research in Sweden, it is felt that a few remarks should be made about the historical background, as well as the main objectives of our efforts in aeronautics and, in particular, of the present research activities.

In limiting the scope of the paper mainly to research activity in a technical sense it would, obviously, still be impossible to give a complete record of all the unclassified research that has been done in recent years without reducing the record to a mere list of headings of reports. It has been preferred to select, more or less arbitrarily, a limited number of investigations, and to give a brief account of each of them, so as to bring out the main points of interest.

Finally, the concept " research " has been interpreted in a rather broad sense. The paper thus deals not only with basic research, but also with many examples of " applied " research, including also such investigations as aim at establishing general design information for future designs of aeroplanes.

2. Historical Background

It might be of some interest to mention first that not only design of aircraft but also, to some extent, aeronautical research, had a fairly early beginning in Sweden, although the very first activities hardly left any important traces in aeronautical history. The famous Swedish scientist and philosopher Emmanuel Swedenborg (died 1772) showed considerable interest in the problem of flying. Further, during the last part of the nineteenth century and in the beginning of this century, a number of Swedish engineers tried to solve this fascinating problem, one of the best known being C. R. Nyberg. He actually built a full-sized aeroplane in 1902 using a specially designed steam engine for driving two propellers. Nyberg also conducted a series of tests with models in a small wind tunnel, but in spite of these efforts, his aeroplane failed to fly.

The first Swedish-built aeroplane that actually flew, did so in 1909. It was designed by Ask and Nyrop, and they were soon followed by other rather successful aircraft designers. By far the most outstanding one was Dr. Enoch Thulin (Fig. 1). As he is considered the great Swedish pioneer, both in aviation and in aeronautical research, a few words on his activities might be of interest[2]. After having obtained his Doctor's Degree, in 1912, with his thesis on " The Air Drag of

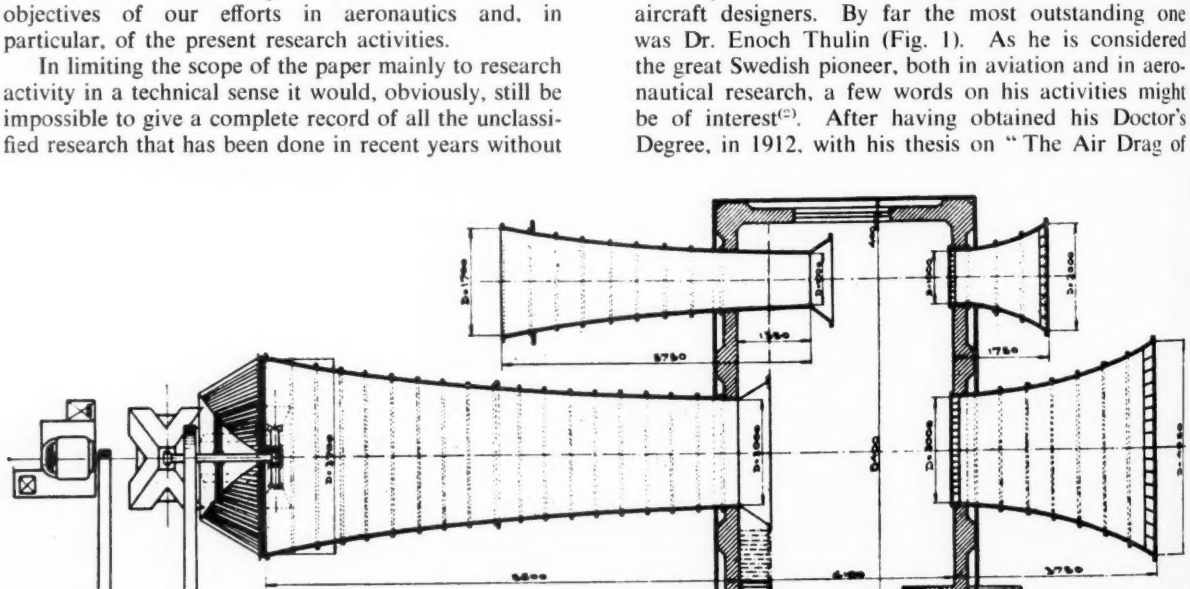

FIGURE 2. Thulin's wind-tunnel plant, 1917, comprising one 6·6 ft. diameter tunnel with an air speed of 100 ft./sec., and one 3·3 ft. diameter tunnel with 160 ft./sec. air speed, driven by a fan and electric motors of 50 and 108 h.p. respectively.

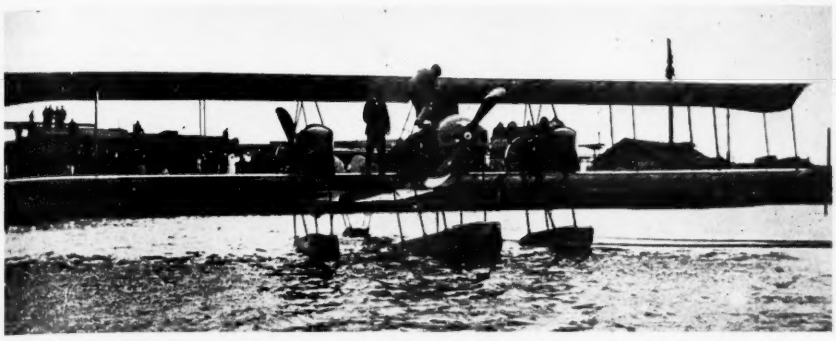

FIGURE 4 (*left*). The Thulin 3-engine bomber and reconnaissance aeroplane, "The Cruiser," 1918 (all-up weight, 4,600 lb.; total power, 270 h.p., and cruising speed 80 m.p.h.).

FIGURE 3 (*below*). The Thulin fighter, "NA," built in 1918. Maximum speed 135 m.p.h.

Thin Plates with Varying Speed," the first scientific aeronautical contribution in Sweden, he founded an aircraft and engine factory in 1913 in the town of Landskrona. The firm grew quickly and was equipped with a wind-tunnel plant comprising two wind tunnels (Fig. 2). There was also a laboratory for testing and research on structures and materials comprising, among other equipment, a fatigue-testing machine.

Altogether no less than 99 aeroplanes of 14 different Thulin-designs and about 700 engines of 6 different Thulin-types were built in the four and a half years the firm was engaged in aircraft production. Figs. 3 and 4 show two of the most successful Thulin aeroplanes, and Fig. 5 the factory in 1918. Dr. Thulin was at the same time manager, chief designer and, for a long time, the only test pilot of his firm, which finally employed some 900 employees. He also made numerous long-distance flights, for instance Paris-Landskrona early in 1914, and in 1915 he founded a Flying School at Ljungbyhed and was its first instructor. Dr. Thulin was killed in 1919 when he crashed while flying his private aeroplane, and his death marked the end of the first promising epoch of the Swedish Aircraft Industry. To his memory a Thulin Medal was instituted in 1944 which is awarded to Swedish citizens for outstanding achievements in aeronautics.

After the First World War the growth of aeronautical activity in Sweden followed, on the whole, the same general pattern and trends as in bigger countries. To begin with, this activity, however, was rather unimportant. The few aircraft firms that were established had a rather difficult and strenuous existence, but nevertheless there was usually more than one firm at the same time. This situation was gradually changed after the foundation of the Royal Swedish Air Force in 1925 and, when a substantial expansion of the Air Force was decided upon in 1936, the pre-requisites for a somewhat more thriving aircraft industry were established. At the beginning of the Second World War steps were taken by the Government and the Swedish Air Force to consolidate the design and production of aircraft in one private firm, the Saab Aircraft Company. About the same time, however, the Air Force found it necessary to establish a design office and factory of its own for the design and production of a fighter aeroplane, the J 22[3], (Fig. 6). This design is mentioned because it marks the end of the second phase

of Swedish aeronautics when it was still possible to design an advanced aircraft mainly on the basis of experience and intuition; for instance, no wind-tunnel test results supported the design of the J 22.

This short, superficial review has led to the present post-war period of transonic and supersonic speeds, when the design of aeroplanes has become more of a science and less of an art, and a well established organisation for the Swedish Aircraft Industry together with research facilities, has been formed.

3. Objectives

The objectives of aeronautical research in Sweden are, at the present time of political tension, mainly determined by defence considerations, and these are to a large extent influenced by the fact that Sweden is not a member of N.A.T.O. The main goal for Swedish aeronautics is therefore to make possible the equipment of the Air Force mainly with aeroplanes of Swedish

FIGURE 5. The Thulin Aircraft Factory in 1918.

FIGURE 6. The "J 22" fighter of 1942. The Royal Swedish Air Force's own design and production. Maximum speed 360 m.p.h. with 1,000 h.p. Pratt & Whitney Twin Wasp engine.

FIGURE 7. The Saab-29, single-seat jet fighter.

make, designed to fit the country's particular tactical and strategical needs and conditions and, at the same time, to be competitive with the military aeroplanes of a potential enemy. Figs. 7-9 of some recent Saab aeroplanes may serve as illustrations of the final products aimed at.

The goal is certainly a very far-reaching one for a comparatively small country, considering the tremendous pace of modern aeronautical development. Just how difficult the goal is to attain might be clearly understood by a comparison of the conditions in Sweden with those of countries with greater industrial resources, for instance Great Britain. Whereas in Great Britain the final decision on quantity production of a new type of military aeroplane can be based on a choice between two or more new different designs, the qualities of which have been firmly established by extensive test flying of prototypes, we in Sweden cannot afford to carry through the design of more than one new type of military aeroplane simultaneously, and such designs are normally spaced with intervals of between three to four years. This restriction makes it imperative that each new design must be a complete success, as it is clear that a "near success" is easily equivalent to a failure.

This unconditional demand of success for each new design has, of course, become greatly aggravated by the transonic and supersonic speed ranges and with the rapid progress on more and more powerful engines. Only one of a great many widely different main principles of design (delta wing, thin straight wings, vertical take-off, etc.) can be chosen and with such a choice only one of a multitude of detailed aerodynamic configurations, structural layouts and kinds of material can finally be applied. To make the correct choice becomes still more complicated because the rather appreciable interval between our new designs means that a very big step in development must be taken each time in order to keep pace with foreign progress.

To achieve this extraordinarily difficult goal extensive research on a high level is undoubtedly of eminent importance; in fact we would be justified in doing more research and preliminary project investigations than if new prototypes could be turned out more often and with a number of parallel designs each time. However, we are fully aware that insufficient funds and personnel have prevented us from building up a research capacity of a size that would be desirable. This fact has compelled us to concentrate most of our efforts on applied research aiming at establishing design information directly applicable to such aerodynamic configurations and kinds of structures as can be visualised for the types of fighters, ground-support aeroplanes and guided missiles required by the armed forces in the near future.

In spite of this urgent need for applied research, as well as for pure testing, we do understand that merely conducting applied research planned as a part of development work in the long run would lead to stagnation. We are, therefore, devoting a necessarily smaller, but substantial, portion of the total research capacity to basic research and to applied research of a more general nature, the reasons being

(*a*) that experience shows that such research often opens up, sometimes rather unexpectedly, possibilities to real progress;

(*b*) that general research is a necessary condition to enable us to understand fully and to utilise the available scientific results from abroad;

(*c*) that the possibilities of acquiring and keeping first class scientists, who are needed to conduct all the necessary applied research and testing, would be greatly impaired by not giving them some opportunities to conduct basic and other more independent research;

(*d*) that our possibilities of exchanging scientific information are highly dependent on the quality and quantity of our own contributions.

We are, naturally, fully aware that the scientific contributions we can make are very limited in relation to the vast amount of research done outside Sweden, as is so impressively demonstrated by the tremendous and ever-increasing flow of aeronautical publications. We certainly cannot cover the whole field, hardly even any major part of it, so instead we have mostly to make rather sporadic contributions by investigating particular problems, selected more or less at random.

FIGURE 8. The Saab-32, Lansen (The Lance), two-seat jet attack aircraft.

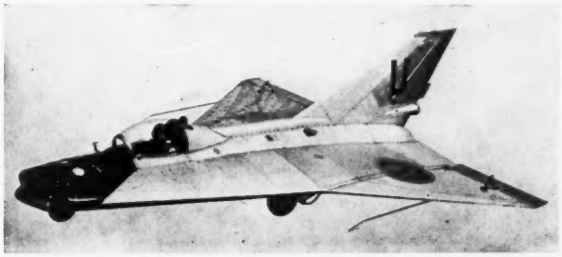

FIGURE 9. The Saab-210, Draken (The Dragon), delta-wing experimental jet aircraft.

4. Organisation

Although military demands have set their stamp on the objectives for aeronautical research in Sweden during and after the Second World War, the organisation of this activity is to a large extent designed according to the civil and commercial aspects consistent with a more peaceful world. This is indicated by the fact that the main Swedish establishment for aeronautical research and testing, the Aeronautical Research Institute of Sweden (F.F.A.), has a civil status and comes under the jurisdiction of the Ministry of Commerce.

The F.F.A. has two aerodynamic departments, one for subsonic and transonic research and testing, the main equipment being two continuous-flow wind tunnels, and the other for transonic and supersonic investigations, its testing facilities comprising the new so-called supersonic wind-tunnel plant. Then there is a Structures Department mainly dealing with research and testing connected with the development of airframes and a Physics Department which, in the first place, assists the three other technical departments in solving their measurement problems and, secondly, conducts independent research on measurement techniques.

The total number of personnel at the F.F.A. is around 250, including a technical staff of 140, of which 35 have university degrees, and about 70 are workmen.

Besides the F.F.A., the Royal Institute of Technology in Stockholm (Kungl. Tekniska Högskolan—K.T.H.) and the Saab Aircraft Company at Linköping are carrying out research in aerodynamics and aeroplane structures and the Svenska Flygmotor AB at Trollhättan and the AB Bofors armament factory at Karlskoga are conducting experimental aerodynamic research and testing in their wind tunnels. A certain amount of engine research and development is done both at Svenska Flygmotor and at Svenska Turbinfabriks Aktiebolaget Ljungström (STAL) at Finspang. A map of Sweden showing the location of the main centres of aeronautical research is shown in Fig. 10.

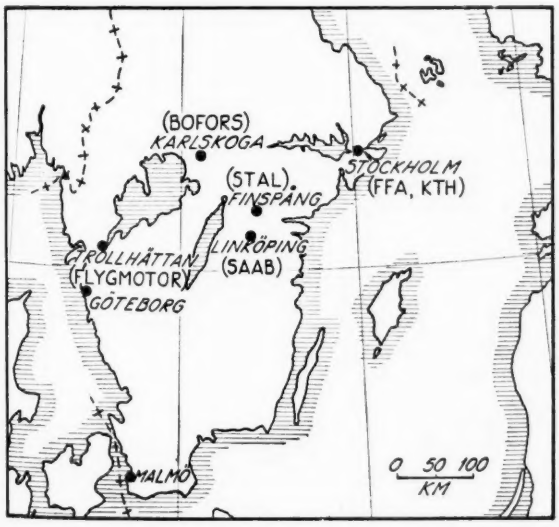

FIGURE 10. Map showing the location of the main centres of aeronautical activity in Sweden.

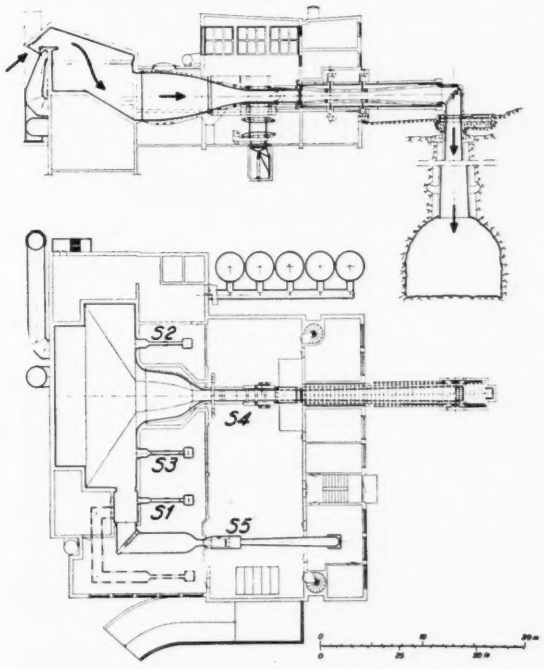

FIGURE 11. The supersonic wind-tunnel plant at F.F.A.

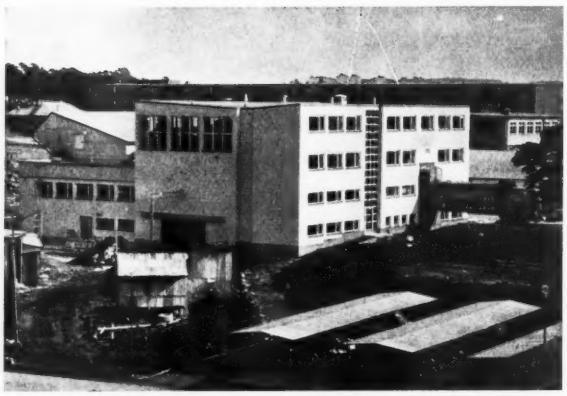

FIGURE 12. The laboratory building for the supersonic wind-tunnel plant at F.F.A.

5. Aerodynamic Research Facilities and some Investigations

5.1. THE AERONAUTICAL RESEARCH INSTITUTE—F.F.A.

5.1.1. *Wind Tunnels*

The Low-Speed Tunnel is of conventional, continuous-flow type with a circular test section of 12 ft. diameter and a contraction ratio of 4·5:1. The fan is driven by a 1,300 h.p. motor giving a maximum wind velocity of 300 ft./sec. To enable investigations to be made where suction is required, *e.g.* in air intake tests, a pipe line has been laid from the tunnel to the big vacuum tank for the supersonic plant.

The High-Speed Subsonic Wind Tunnel is also of the continuous-flow type with a circular test section of 3 ft. 4 in. diameter and a contraction ratio of 9:1. There are two fans, each driven by a separate motor, the total effect being 3,200 h.p. Mach numbers up to 1·0 without model can be obtained and the pressure can be varied from 0·15 to 1·0 ata (2·13 to 14·2 p.s.i.) in the pressure chamber. A water cooler with 7,700 ft.² cooling area limits the maximum stagnation temperature to about 45°C.

The Supersonic Wind-Tunnel Plant is illustrated in Figs. 11 and 12. The wind tunnels work on the vacuum principle and they are installed between a large drier, shown on the left of Fig. 11, and a series of vacuum tanks. At present the plant incorporates the following 5 tunnels:

Tunnel	*Area*	*Dimensions*	
S 1	0·026 m.² (0·28 ft.²)	16×16 cm.	(6·3× 6·3 in.)
S 2	0·026 m.² (0·28 ft.²)	8×32 cm.	(3·2×12·6 in.)
S 3	0·072 m.² (0·78 ft.²)	24×30 cm.	(9·5×11·8 in.)
S 4	1·04 m.² (11·2 ft.²)	0·9×1·15 m.	(2·9× 3·8 ft.)
S 5	0·26 m.² (0·28 ft.²)	0·45×0·575 m.	(1·5× 1·9 ft.)

The test section of the 1 m.² tunnel, S 4, is shown in Fig. 13.

The vacuum system comprises two main containers, with volumes of 9,000 m.³ (317,000 ft.³) and 2,000 m.³ (70,000 ft.³), which were blasted out of the rock 25 m. (82 ft.) below the laboratory building, and five steel containers with a total volume of 230 m.³ (8,100 ft.³), located at the side of the building.

The two largest tunnels, S 4 and S 5, are normally connected to the 9,000 m.³ and the 2,000 m.³ rock chamber respectively, and thus the two tunnels can be run independently. There are, however, also provisions for connecting each tunnel to the total volume of 11,000 m.³, whereby increased running time can be obtained. The maximum running time for the S 4 tunnel when connected to the 9,000 m.³ chamber, is about 30 seconds for Mach numbers around 1·0 and at

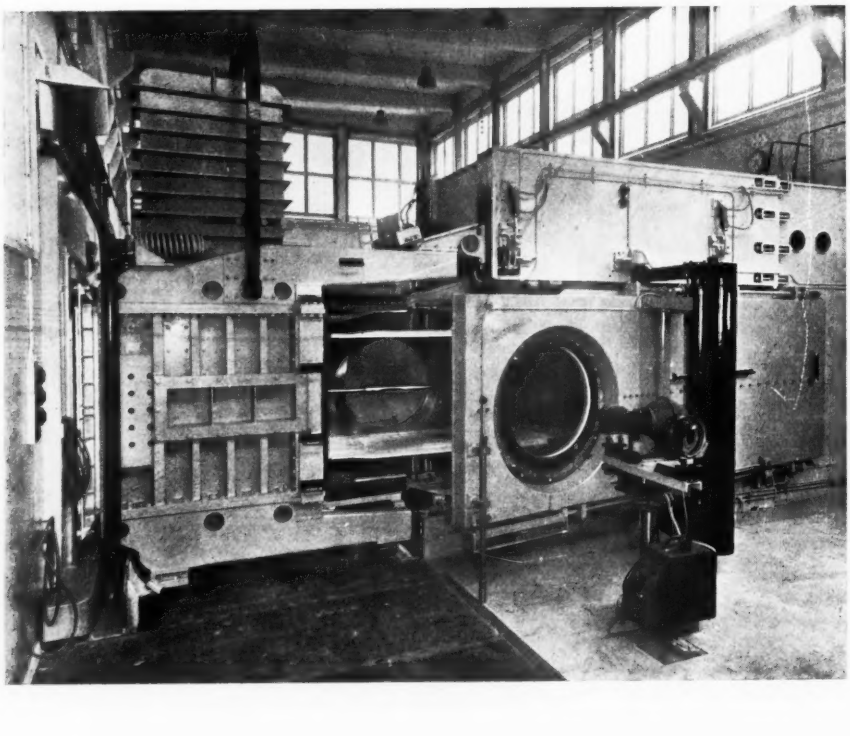

FIGURE 13. The test section of the 1 m.² supersonic wind-tunnel (S 4) at F.F.A.

an initial pressure in the chamber of 0·2 ata (2·85 p.s.i.) and this time decreases to about 20 seconds at $M = 2{\cdot}5$. The most economical operation is normally obtained by limiting the evacuation to a pressure of around 0·7 to 0·5 ata. The running time will then be limited to between 8 and 15 seconds.

The rock chambers are evacuated by means of three vacuum pumps of the Lysholm screw type of 450 h.p. each and with a maximum pressure ratio of 10:1. The pumping time to 0·1 ata in the largest chamber is about 30 minutes, but for a pressure of 0·6 ata, the pumping time is reduced to about 5 minutes.

The three smaller tunnels, S 1, S 2 and S 3, can be connected either to the steel containers or to one, or both, of the rock chambers. A special high vacuum pump is capable of evacuating the steel containers to 0·05 ata, permitting Mach numbers in the small tunnels of about 5·0. When connected to the large rock chamber, the small tunnels have, in fact, no limitations in running time.

The drying plant consists of a main drying bed of 210 m.² (2,300 ft.²), filled with about 30 tons of Silica gel, and two auxiliary beds for reactivation and cooling of the main bed. The drying plant dries the air to a maximum humidity of 0·5g moisture per kg. air.

This wind-tunnel plant was primarily intended for supersonic investigations. For the transonic field another scheme was planned some years ago, but so far no funds for it have been granted. This has compelled us to utilise the supersonic plant for transonic research and testing also, and this is the reason why most of the tunnels are equipped with replaceable "blocks" with ventilated walls.

5.1.2. *Some Investigations*

In the low-speed field the research in later years has mainly been devoted to studies of the flow patterns and of the aerodynamic qualities at low speeds of wings of high-speed plan-forms such as swept-back and delta wings.

In order to study the flow in detail around swept wings the "paint test" method has been extensively used, and it has yielded rather interesting possibilities to explain certain instability effects. Fig. 14 shows two typical results from paint tests for a wing with a double swept leading edge, together with corresponding pressure measurements. Fig. 14(*A*) indicates that, at a moderate angle of attack, two separate vortices exist, one originating at the front portion of the very highly swept inner part of the wing and the other originating close to the corner between the two straight leading edges. At a higher angle of attack these two vortices begin to interfere with each other, as shown in Fig. 14(*B*). This interference leads to a loss of lift at the rear outer part of the wing, which results in a forward movement of the centre of pressure. The two points, *A* and *B*, on the moment curve correspond to the two angles of attack. It is obvious that the combination of balance measurements and paint tests can yield essential information and thus be of value when designing wings for attaining good stability qualities at high angles of attack.

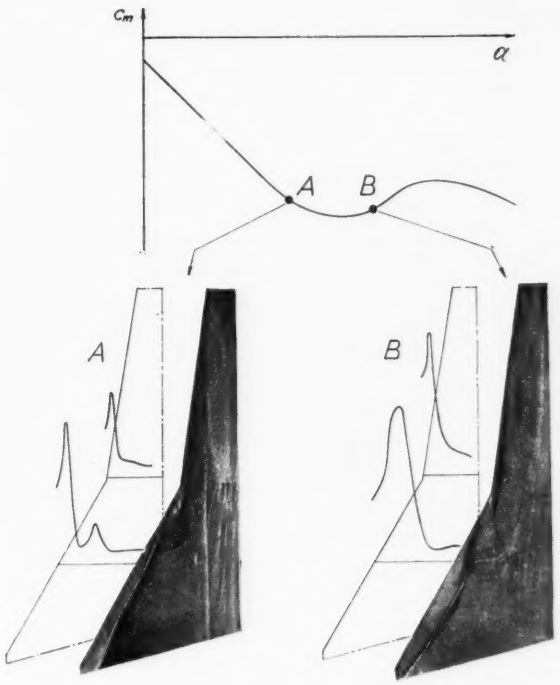

FIGURE 14. Paint test patterns at low speed on the suction side of a wing with a double-swept leading edge at two different angles of attack together with corresponding pressure distributions and pitching moments.

Another investigation in this speed range has dealt with the interference between a delta wing and vertical fins of various configurations[4]. Wind-tunnel tests had shown that the increment in rolling moment, at an angle of yaw, due to the presence of a vertical fin is much smaller than could be expected by the side force on the fin. This is explained by the fact that the suction on the suction side of the fin increases the lift on the adjoining part of the wing, which causes an increment in rolling moment counteracting that due to the side force on the fin.

In the high subsonic speed range the paint test method has also been applied. An example is shown in Fig. 15 for a half-model comprising a swept wing and a horizontal tailplane (not shown) at $M = 0{\cdot}8$. At a certain, rather moderate angle of attack (*A*) a leading edge vortex arises, which soon becomes rather strong (*B*). This vortex is not attached to the entire length of the leading edge it separates, in fact, from the surface at a certain point at this edge, this point is located nearer the wing root, the more the angle of attack is increased (*B* and *C*). By this separation a larger and larger part of the outer wing will be covered by a region of forward flow on the suction side as the point of separation approaches the wing root (*E*). This implies that the wing tip loses lifting force resulting in a growing positive (nose-up) pitching moment in full

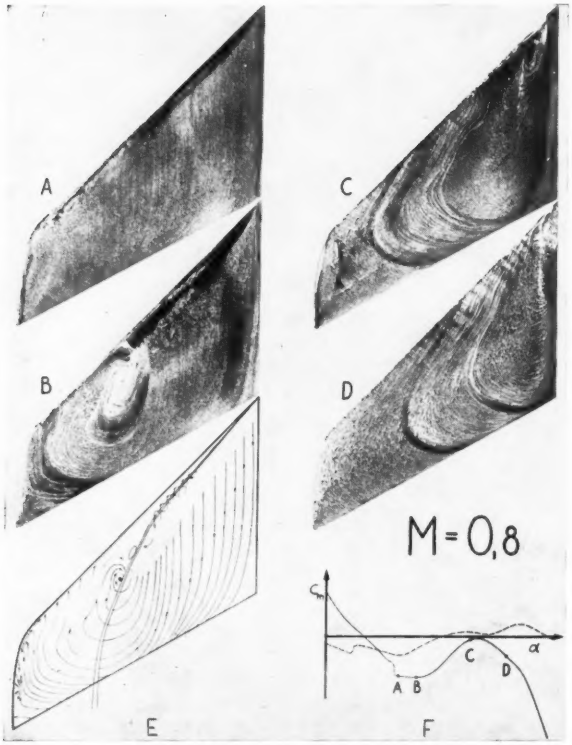

FIGURE 15. Paint test patterns on the suction side of a half-model wing at high subsonic speed for a series of angles of attack.

agreement with the course of the dotted line in the moment diagram, (*F*), valid for a model without a tailplane. Besides this, the vortex core, which with increasing α moves inward and upward, induces a heavy down wash at the tailplane, which explains the shape of the moment curve for the complete model. At the maximum point of this curve the vortex core has reached the neighbourhood of the tailplane tip and when the angle of attack is increased still more, (*D*), the paint pattern indicates that the vortex core has moved farther towards the plane of symmetry of the model and has been appreciably raised from the wing surface. As a result the downwash at the tailplane is reduced and the moment curve reassumes its original slope.

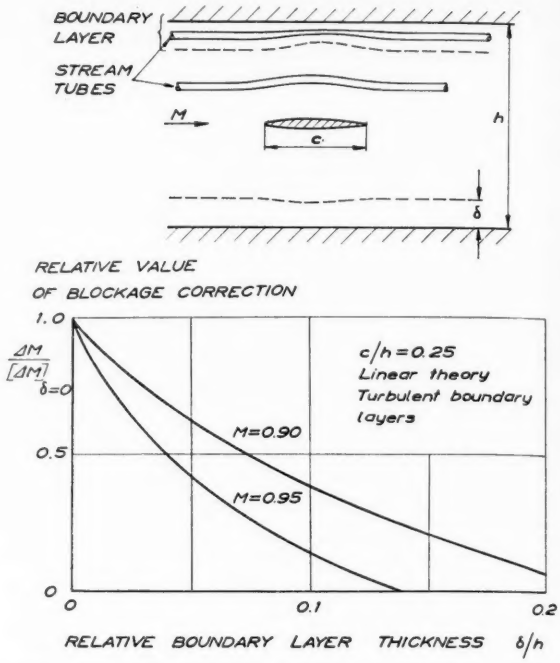

FIGURE 16. Boundary layer influence on blockage correction.

A substantial part of our research efforts in the high subsonic, as well as in the pronounced *transonic speed range*, has aimed at the reduction and, eventually, elimination of the blockage effect. One approach has been some experimental and theoretical studies of the boundary layers of wind-tunnel walls[5, 6, 7]. By means of drag measurements on symmetrical, two-dimensional wing models

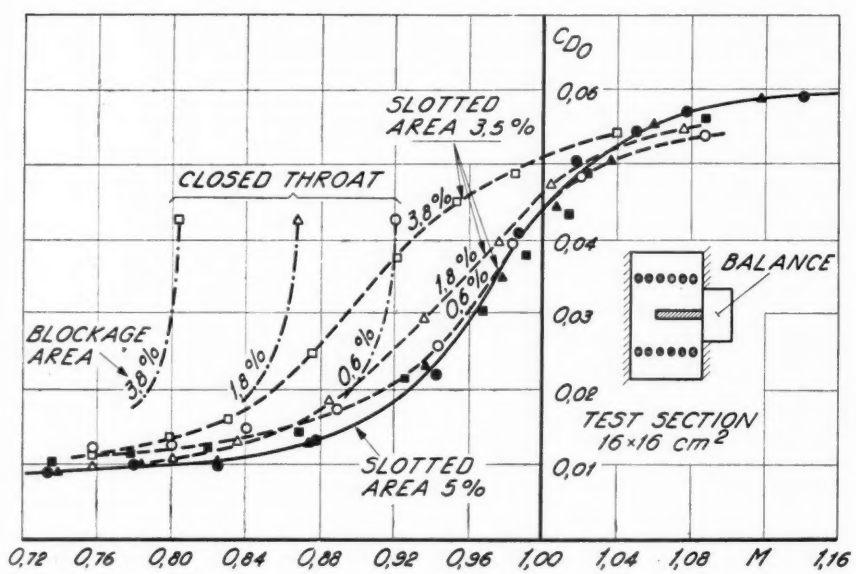

FIGURE 17. Half-model tests with a straight wing (aspect ratio 2·1 and N.A.C.A. 0009-0·55, 40 profile) in a wind tunnel with slotted walls.

and bodies of revolution it was found that a thickening of the boundary layer resulted in an appreciable reduction of the interference from the tunnel walls or, in other words, an increase of the choking speed. Briefly stated, this phenomenon is explained by the fact that the stream tubes within the boundary layer are able to contract more before choking than the stream tubes outside the layer (Fig. 16). This, obviously, means that the boundary layer makes the wall appear flexible, whereby the slope of the stream lines at the wall approaches that at free flight. The theoretical studies of this matter are exemplified by the two curves in Fig. 16, which indicate the effect of thickening the boundary layer, at $M=0{\cdot}9$ and 0·95. According to the applied theory it would be possible, at least for a certain part of the subsonic speed range, to eliminate wall interference by thickening of the wall boundary layer, but in practice an appreciable reduction is probably the most that can be hoped for.

Another approach to the solution of this problem was based on the well-known fact that the boundary surfaces of a closed throat tunnel cause an increase of the flow velocity at the model, while the opposite effect is obtained with an open throat tunnel. It was thought that these two effects could be made to compensate each other by employing slotted walls, and in 1950 some rather promising tests were conducted with walls which were slotted by means of deep longitudinal recesses[8].

While these tests were being made some information was obtained to the effect that a tunnel with slotted walls of a somewhat different shape could be run right through the transonic speed range without blockage, by means of an appropriate shaping of the rear portion of the slotted walls so that a suction of the air through the slots is obtained. Intensified tests and studies were made, and early in 1952 ventilated walls of a successful type were installed in the two-dimensional tunnel (S 2).

In all these investigations the guiding criterion for correct flow conditions, *i.e.* conditions similar to those at free flight, has been that geometrically congruent models of different sizes shall have the same drag coefficient. In particular the correct relative slot width has been determined by this requirement. An example of a series of tests resulting in the determination of the correct slot width is shown in Fig. 17. Fig. 18 shows some results for a half-model and a wing with a trapezoidal plan form, tested in the S 3 tunnel. The two new wind tunnels, S 4 and S 5, are also equipped with slotted walls which are incorporated in replaceable

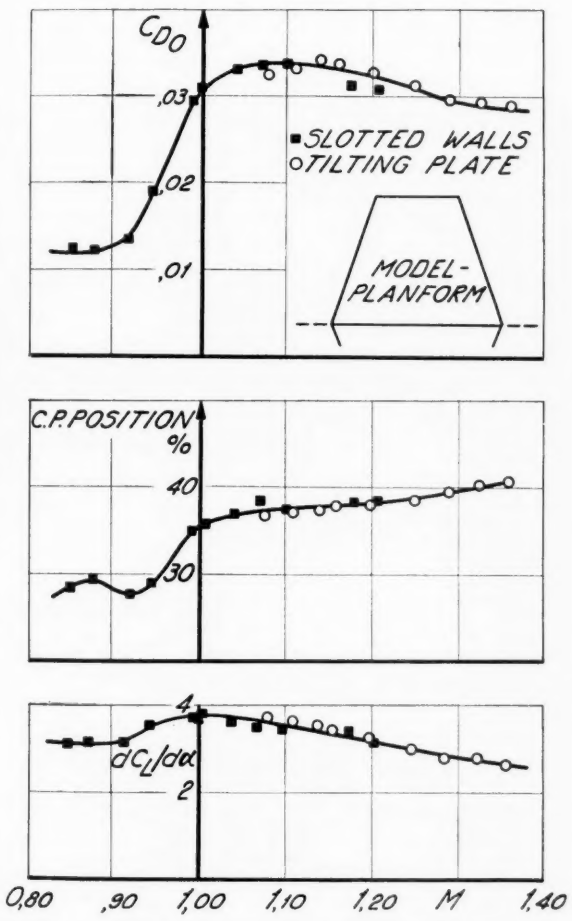

FIGURE 18. Half-model tests with a trapezoidal wing; aspect ratio 2, taper ratio 0·5, and 6 per cent. thick circular-arc profile.

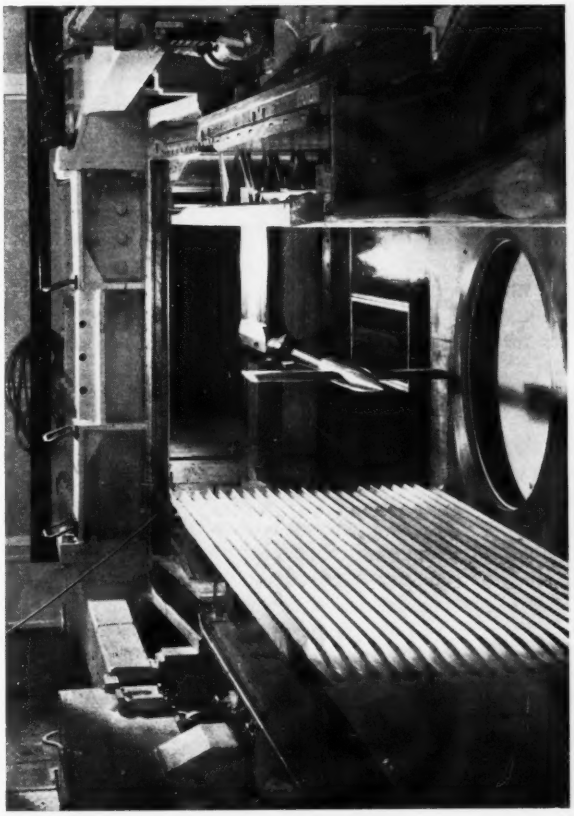

FIGURE 19. Slotted walls incorporated in replaceable blocks in the F.F.A.'s new 1 m.² tunnel.

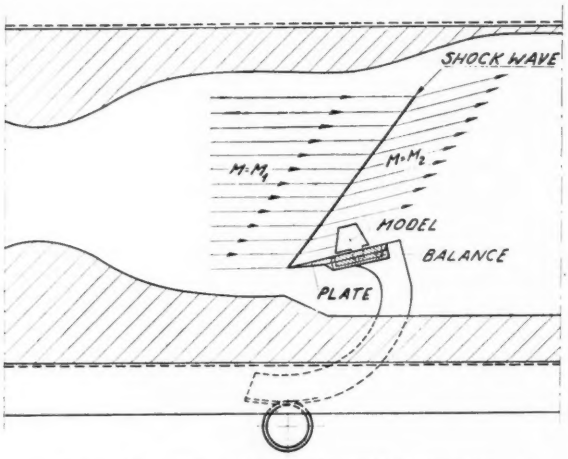

FIGURE 20. Sketch of test section with tilting plate.

blocks. Fig. 19 shows the present form of the slotted walls in the 1 m.² tunnel (S 4).

In *the field of supersonic aerodynamics*, the development of the Tilting Plate for continuous variation of the Mach number might first be recalled [9, 10]. The method is based on the fact that in a uniform and parallel supersonic stream with a certain Mach number, the deflection of the flow at a two-dimensional corner takes place in such a way that after the deflection the flow is again uniform and parallel but has another Mach number. For a concave corner, the deflection takes place along the straight shock wave originating at the corner. The Mach number is reduced and its magnitude is uniquely dependent on the initial Mach number and on the angle of deflection. These aerodynamic laws were applied and utilised by inserting a sharp-edged wedge or plate in a supersonic wind tunnel and by using the plate as a mounting for models (Fig. 20). In general the results obtained are rather good. Fig. 18 shows that the test points fit rather well with results obtained in a ventilated test section. The method has also been used by the Royal Aircraft Establishment and the N.A.C.A.[11, 12].

Another investigation, which is also of a rather basic character, is of some studies of the influence of strong adverse pressure gradients on turbulent boundary layers at supersonic speeds[13]. The flow in a concave corner was studied, by means of schlieren pictures and pressure measurements, for various values of boundary layer thickness, Mach number and Reynolds number. It was found that the pressure jump through the shock necessary for producing separation at a given Mach number is independent of the Reynolds number. It was found that the size of the separated region is uniquely determined by the boundary layer thickness and the pressure jump of the shock, independent of the Reynolds number based on the boundary layer thickness (Fig. 21). Thus, once turbulent boundary layer flow is established in a wind tunnel test, the sole parameter determining scale effects on the inter-action between shock-wave and boundary layer seems to be the thickness of the boundary layer relative to model size. These observations seem to be of importance for the interpretation of certain supersonic flow phenomena, for example at wing trailing edges and deflected flaps. This investigation is similar to, and agrees well with, certain parts of the well-known investigations on shock-wave boundary layer inter-action by Holder and Gadd in England.

The studies in supersonic flow have also led to the development of a method for determining the wave drag from the shape of the bow wave[14]. This method is based on the theory for the calculation of the wave drag[15] (and others), and implies, in the first place, that the detailed course of the shock wave is determined by schlieren photographs and correlated to certain simplified, yet accurate, mathematical expressions. The part of the shock wave which at free flight conditions would extend outside the tunnel is determined theoretically on the basis of the photographed part. The method is convenient to use, in particular, for axially symmetrical bodies and is of value mainly when the wave drag, or changes in this part of the total drag, are of primary interest, for instance in studies of the influence of variation of the mass flow in air intakes on the wave drag.

Detailed studies of the flow at the suction side of delta-shaped wings have also been conducted in the supersonic speed range[16]. Such investigations have been made with wings with a sharp leading edge, where strong vortices are easily created. Paint testing has been supplemented both by surface pressure measurements

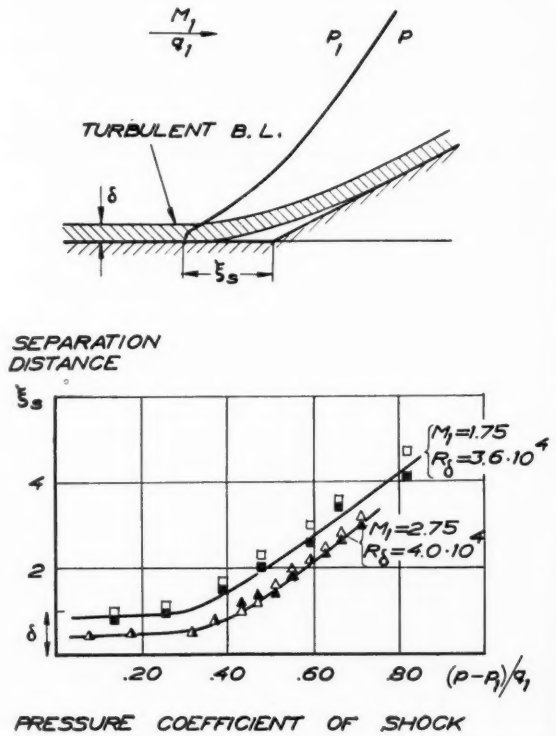

FIGURE 21. Separation distance ξ_s in terms of boundary layer thickness as a function of the shock pressure coefficient.

and by measurements of the flow direction by means of a specially developed probe. Fig. 22 shows an example of results obtained at a Mach number of 1·5. The correlation of the three methods, in the first place as regards the location of the vortex core, is demonstrated rather clearly by this figure. It might be pointed out that as long as the flow over the leading edge is subsonic (which occurs when the apex angle is smaller than the shock angle), the flow pattern is rather similar to that of pure subsonic flow.

In *the field of unsteady aerodynamics* several experiments on damping derivatives have been made in subsonic and supersonic flow as well as in transonic flow[17, 18]. The experiments were made according to the free oscillation method. The main disadvantage with this method, the tedious evaluation of results, has been overcome by the development of a special apparatus called the "Dampometer." This instrument, the principles of which are described in Section 7, enables automatic evaluation of the logarithmic decrement and the frequency of damped harmonic oscillations simultaneously with the test. It might be mentioned here that the Dampometer also permits the evaluation of the logarithmic decrement when the damping varies with amplitude and when the damping is negative.

For these investigations a special apparatus was developed for tests with semi-span models in high speed wind tunnels. This apparatus comprises an elastic, cross-sectioned torsion bar, to which the model is attached, and an electromagnetic driving unit. An initial oscillation is given to the model by this unit, the energy source is then suddenly disconnected and the resulting free oscillation is electrically transmitted to the Dampometer. Some of the results obtained with this technique on a 6 per cent. thick triangular wing are shown in Fig. 23, where a comparison is also made with some theoretical results for thin wings. In the transonic speed range a slotted test section was used. It is interesting to observe the sudden drop of damping at a Mach number of one and to compare the experimental and theoretical values. The agreement is good at a Mach number of one, but in the supersonic range a discrepancy can be noted, the reason for which remains to be found. The theoretical results at Mach number 1·0 and at supersonic speeds have been obtained at K.T.H. and F.F.A.[19, 20]. Similar investigations have also been made for obtaining the damping-in-pitch of two-dimensional wings and the damping-in-roll of complete three-dimensional models.

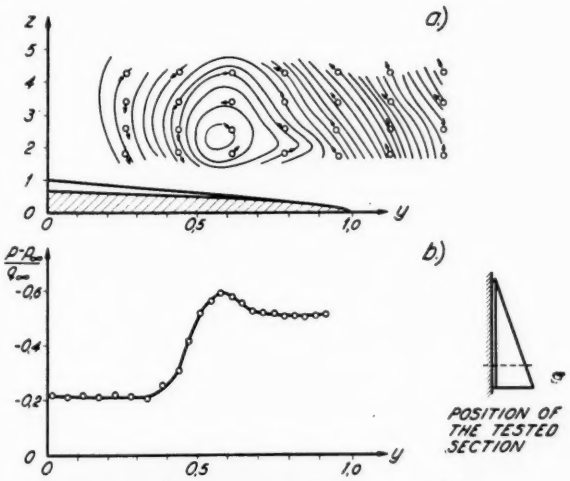

FIGURE 22. Flow investigation in a span-wise section on the suction side of a 70° delta wing at $M=1{\cdot}5$ and $\alpha=15°$ carried out by (*a*) flow direction measurements (*b*) pressure distribution measurements and (*c*) paint test.

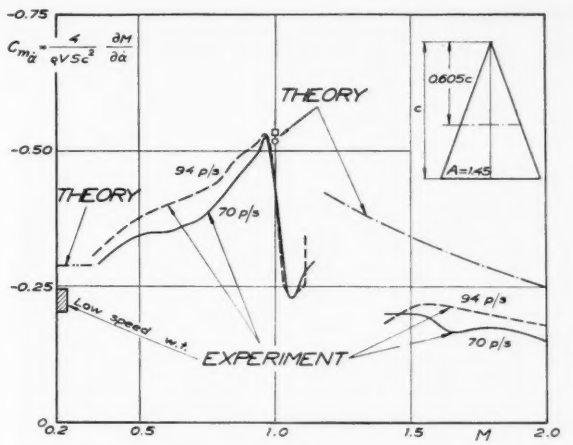

FIGURE 23. Damping-in-pitch derivative, $C_{m\dot{\alpha}}$, for a triangular wing of aspect ratio 1·45.

At high reduced frequencies the experimental determination of stability derivatives in high speed wind tunnels becomes rather difficult, as very high absolute frequencies have to be used. If, for example, the Mach number is 2·0 and the stagnation temperature is 20°C. in the test section, then at the reduced frequency $2\pi c\nu/V=0{\cdot}5$ and for the chord length $c=0{\cdot}1$ m. (4 in.) a frequency of no less than $\nu=400$ c.p.s. is required. To avoid this difficulty in two-dimensional supersonic flow, the idea suggests itself of using the analogy between the free surface liquid flow and the two-dimensional supersonic gas flow. A simple test apparatus for such measurements has been developed, and we hope to be able to use it also for some quantitative measurements (Fig. 24).

At the F.F.A. we do not normally conduct investigations in the field of general performance analysis, but during the later years of the Second World War, and for some time afterwards, some theoretical studies were made to clarify the inherent possibilities of jet propulsion and its general implications in respect of optimum design. These studies originated with an investigation in 1944 on behalf of the Royal Swedish

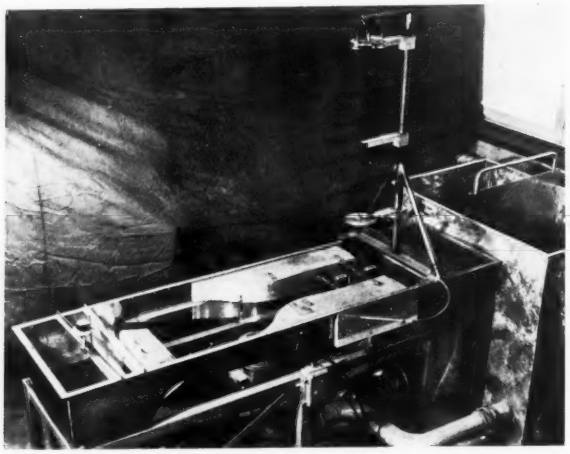

FIGURE 24. Water channel for oscillation tests using the hydraulic analogy for plane supersonic flow.

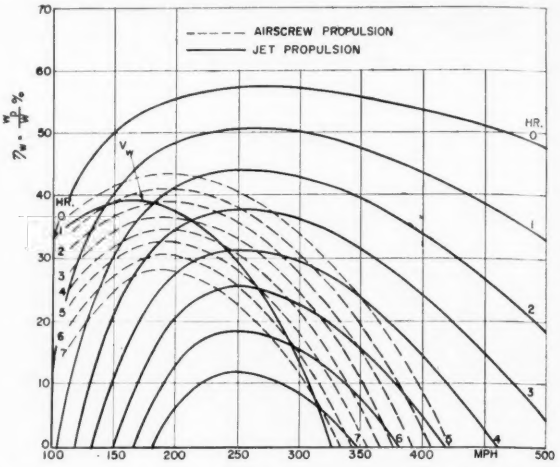

FIGURE 25. The payload ratio *versus* speed with jet and airscrew propulsion for different durations at an altitude of 23,000 ft. and a wing loading of 41 lb./sq. in. V_W = equivalent speed.

Air Force, following news of Air Commodore Whittle's successful pioneer work on jet propulsion. The object of this study[21, 22, 23] was to find out whether or not it was likely that jet propulsion would eventually replace piston-engine airscrew propulsion for various classes of aircraft. The main difficulty with such a comparison was that the two means of propulsion are characterised by widely different qualities, as *power* (h.p.) is, at least nearly, constant with speed, and therefore the characteristic concept, for piston-engine propulsion, whereas *thrust* (lb.) is nearly constant with speed for jet propulsion. It was therefore found to be impossible to compare the two means of propulsion merely on engine data, and instead, a comparative study of the performance of the entire aeroplane had to be made. To make this possible, it was further necessary to define a simple figure of merit for the complete aeroplane equipped alternatively with the two types of power plants. One of the most appropriate concepts in this respect was deemed to be the payload ratio, *i.e.* the payload divided by the gross weight, plotted against speed. A general equation for this figure of merit valid for the complete aeroplane was derived by combining general weight equations for the main components and equipment of the aeroplane with the common performance equation for forward speed. The result of this analysis is exemplified by Fig. 25 which indicates that jet propulsion is superior to piston engine propulsion at such surprisingly low, equivalent, cruising speeds (V_W) as from 150 to 250 m.p.h., depending on duration.

This theoretical investigation contributed to an early appreciation in Sweden of the great inherent possibilities of jet propulsion and it also contributed to the interruption at an early stage of an ambitious 24 cylinder piston-engine project.

Investigations along similar lines of thought were then conducted at the F.F.A. to obtain optimum design features for jet aeroplanes, for instance the optimum aspect ratio and the net gain in lift due to high lift devices when their weight is considered[24, 25].

5.2. THE ROYAL INSTITUTE OF TECHNOLOGY—K.T.H.

The Division of Aeronautics at the Royal Institute of Technology is supplemented by the Aeronautics Laboratory, which conducts theoretical and experimental research besides the normal academic activity of the Division. It has mainly the following wind tunnels.

One 3·26 m.² (7 ft. × 5 ft.) octangular closed section low-speed tunnel of 125 h.p. and a maximum speed of 120 ft./sec.

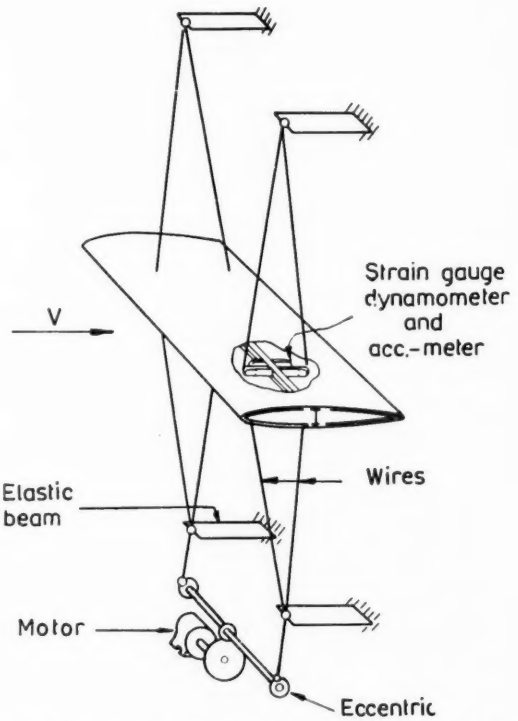

FIGURE 26. Test set-up for a two-dimensional wing oscillating in vertical translation at low speeds.

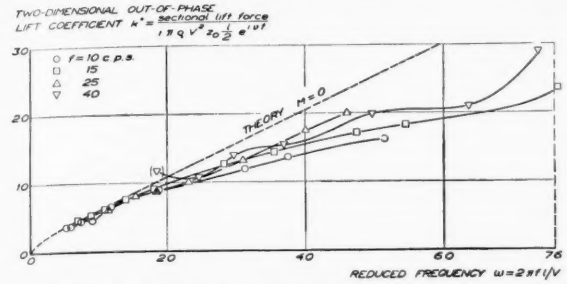

FIGURE 27. Two-dimensional lift coefficient k'' for oscillation in vertical translation.

One 0·11 m.² (13 in. × 13 in.) closed circuit supersonic induction tunnel primarily intended for Mach numbers between 1·15 and 1·8 and a stagnation pressure of 1 ata (14·2 p.s.i.). This tunnel is also being equipped with a test section comprising ventilated walls for transonic speeds.

One 0·047 m.² (8·5 × 8·5 in.) blow-down tunnel for Mach numbers up to 3 and with a permissible stagnation pressure of about 10 ata (140 p.s.i.) for a Mach number of around $M = 1·0$, and 20 ata (280 p.s.i.) for $M = 2·0$ or higher.

The two last mentioned tunnels are driven by compressed air from a high-pressure compressor plant, comprising two 135 h.p. compressors which charge a number of torpedo air vessels of 8 m.³ (280 ft.³) to a maximum pressure of 140 ata (2,000 p.s.i.).

The laboratory also has one 55 × 31 × 31 inch three-dimensional potential tank, which is used for studies of

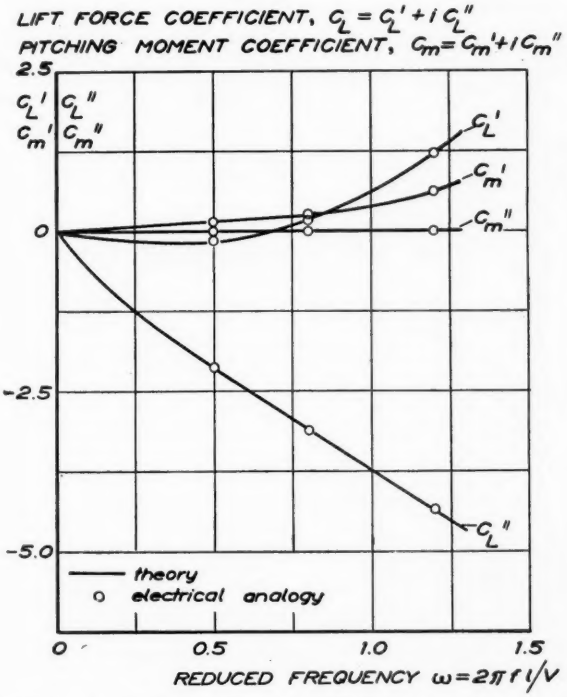

FIGURE 29. Force and moment coefficients at quarter chord for a two-dimensional wing oscillating in vertical translation.

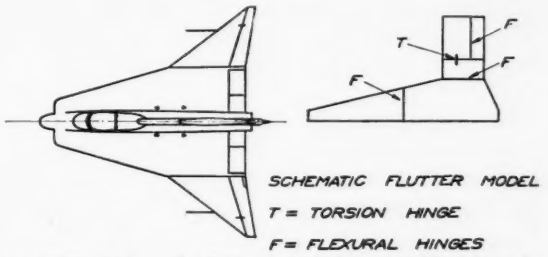

FIGURE 28. Schematic flutter model for a double-delta wing aeroplane.

both stationary and non-stationary flow conditions, and one electronic differential analyser (including 56 units for linear operations and 27 units for non-linear operations), mainly used for stability investigations and performance analysis of aircraft operations.

In the low speed tunnel some preliminary studies have been made in the field of non-stationary aerodynamics. The tests have been confined in the first place to a two-dimensional wing in translatory up and down oscillation. The model was made of balsa wood on a frame of aluminium, and the excitation was achieved by means of forced eccentric movement (Fig. 26). The lift force was measured by unbonded strain gauge dynamometers, and accelerometers, also with unbonded strain gauges, were used to compensate the mass forces. Typical results for the out-of-phase component of the non-stationary lift coefficient are shown in Fig. 27. The discrepancy between the theoretical curve and the experimental points at high reduced frequencies is thought to be due to the boundary layer effects on the position of the rear stagnation point.

In the same tunnel some preliminary flutter research has also been made to increase knowledge about flutter problems introduced by the swept and delta wing plan forms. These investigations have been made with a wing-body combination (Fig. 28) intended to simulate that of a double-delta aeroplane, such as the Draken (Fig. 9). The model was built with the following degrees of freedom: lateral motion of the entire aeroplane, rotation of the aeroplane about the pitch axis, bending in pitch of the aft part of the wing-body, bending of the outer part of the wing, torsion of the outer part of the wing, and rotation of the elevon. The model consists of rigid parts made of balsa wood on a frame of aluminium, connected with flexible links of steel with strain gauges for oscillographic recording of the flutter motions. The stiffness and mass distribution of the model was varied through the exchange of springs and lead weights. It is impossible to give an account of the results in a limited space, but the investigation has been of value as a preliminary study of the complicated flutter modes that can arise with wing, body and flap configurations of the type in question.

As an example of the work done with the potential tank, some non-stationary problems have been studied with this equipment. It had been found[26] that by using a special potential function, the tank could be

FIGURE 30. The Saab wind-tunnel plant.

utilised for investigations concerning incompressible non-stationary flow around a wing, both for arbitrary flutter modes and for arbitrary plan forms. This potential function in a given point is the integral of the acceleration potential from infinity upstream to the actual point. Fig. 29 shows the extraordinarily good agreement with the theory for incompressible non-viscid flow for a two-dimensional case.

Since the method had thus proved its value, it has also been applied to three-dimensional wings, for instance for the determination of the span-wise distribution of the lift and pitching moment coefficients for a rectangular wing with an aspect ratio of 3.

In the field of theoretical aerodynamics a considerable number of investigations have been conducted, both in transonic flow, boundary layer theory and non-stationary aerodynamics[19, 27-33].

This might be the proper place for paying a tribute to Professor S. Luthander, who is the head of the Division of Aeronautics at K.T.H. He and his associates have contributed much to the development of aeronautics in Sweden, not only by educating a great number of people to fill the needs of research and development but also by pioneering new fields of research. As typical examples might be mentioned the development of the aforementioned differential analyser and the investigation of vortex flow over swept wings[34].

5.3. SAAB AIRCRAFT COMPANY

As is the case with several of the main aircraft manufacturers outside Sweden, the Saab Aircraft Company has also found it useful to have a wind tunnel of its own, in particular for tests in direct conjunction with test flying and for preliminary studies in the early design stage of new types of aircraft[35]. This tunnel (Fig. 30) is of the open "jet engine type," the source of power being four Goblin engines located downstream from the test section. The area of the test section is normally 0·5 m.² (2·3 ft. × 2·3 ft.), but it can be changed to 0·7 m.² (3·3 ft. × 3·3 ft.) for supersonic speeds. The speed range is from $M = 0{\cdot}5$ to $M = 1{\cdot}5$.

To avoid condensation, some of the exhaust gas is led back and mixed with the main inflow. As, however, this heating was found to be insufficient, an after-burner has been installed, by means of which the temperature in the settling chamber can be increased to around 120°C. The normal operating temperature is around 65°C.

This tunnel has recently been equipped with ventilated walls designed according to experience obtained at the F.F.A. In order to be able to vary the slot width, the rods comprising the walls have elliptical sections and the slot width can be varied simply by rotating these rods.

Another interesting piece of equipment designed at Saab is the Gradient Tank[36]. This differs from earlier known types as it permits the direct mapping out of the velocity distribution, even for three-dimensional bodies. Although this electrical analogy can only simulate incompressible flow, it can be used advantageously for detailed studies of interference effects and for modifying the configurations of a model so as to avoid peaks in the pressure distribution.

As the activity at Saab is mostly confined to development work mainly of a classified nature, no account of it will be presented here.

5.4. FLYGMOTOR AEROENGINE COMPANY

For the main purpose of providing a storage for compressed air for the testing and development of engines, the Flygmotor Aeroengine Company has built a large compressed air magazine, which also supplies air to some wind tunnels[37]. This unusual air magazine is shown schematically in Fig. 31. It consists of an underground chamber, blasted out of the rock to a volume of 11,000 m.³ (380,000 ft.³). The air in the magazine is under pressure from a water column communicating with the adjoining river through underground tunnels. The magazine is situated 85 m. (280 ft.) below the normal level of the river and the height of the magazine is only 3·8 m. (13 ft.). This height is so small in comparison with the depth below the water surface that the air magazine is practically a "constant pressure tank."

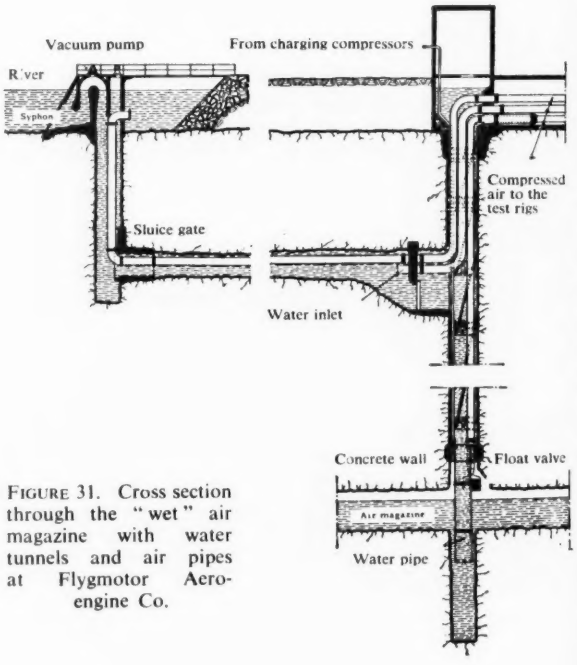

FIGURE 31. Cross section through the "wet" air magazine with water tunnels and air pipes at Flygmotor Aeroengine Co.

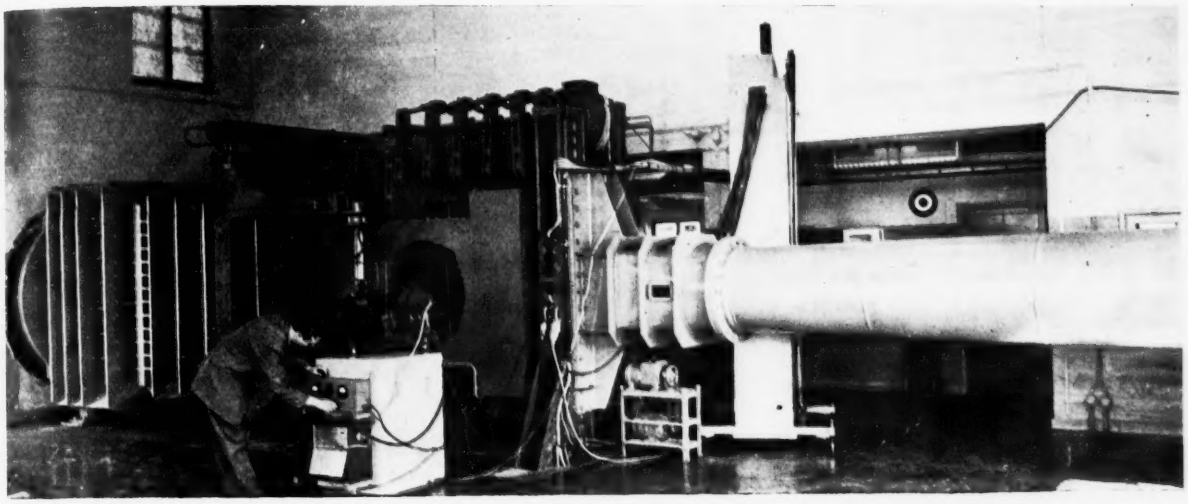

FIGURE 32. The ballistic wind-tunnel at Flygmotor Aeroengine Company. Test section 2·56 ft.², maximum Mach number 3·6.

When the magazine is discharging air, water is taken in from the river through a siphon intake and an 80 m. (260 ft.) long horizontal tunnel to a vertical tunnel down to the magazine. Just above the ceiling of the magazine this tunnel is separated from it by a concrete wall and from there the water passes through a steel pipe to a shaft below the floor of the magazine. The air is forced by the water against the roof and the concrete wall and from there is carried through a 0·6 m. (2 ft.) diameter pipe line in the vertical tunnel to the laboratory pipe line system.

The magazine is charged by three two-stage reciprocating compressors, driven by electric motors with a total of 745 horsepower. The compressed air, which is fed into the magazine through a separate charging pipe, forces the water back into the river. Fully charged, the magazine will hold 130 tons of air at a pressure of about 9·5 ata (135 p.s.i.). It takes about 17 hours to charge the magazine after it has been emptied.

The air in the magazine of course, has a relative humidity of 100 per cent., but owing to the high pressure and the fact that the air is cooled to a temperature nearly the same as that of the river water, the absolute humidity is low. A moisture content of maximum 1·6 g./kg. (0·0256 oz./lb.) air is obtained in summer-time and in winter-time it is 0·6 g./kg. (0·0096 oz./lb.).

There are three wind tunnels connected to the air magazine. The principal one (Fig. 32), which is mainly intended for ballistic research, has a test section of 0·25 m.² area (1·6 × 1·6 ft.). It is equipped with solid nozzles for supersonic speeds up to $M = 3·6$ and with slotted walls for transonic speeds.

A special tunnel has been constructed for air intake and similar tests. It is subsonic with a maximum Mach

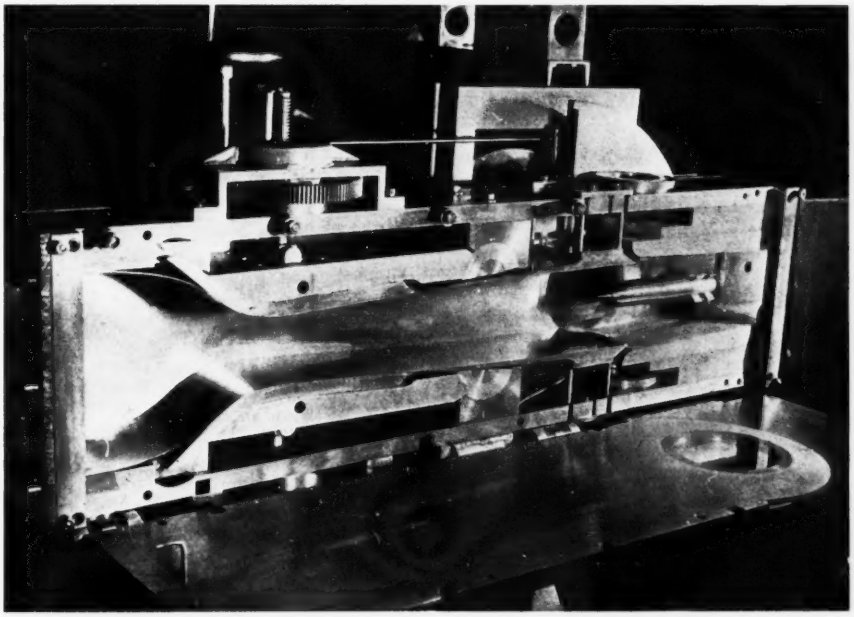

FIGURE 33. In this 6 × 6 in. supersonic tunnel at Flygmotor the Mach number can be continuously varied between 1·5 and 2·8.

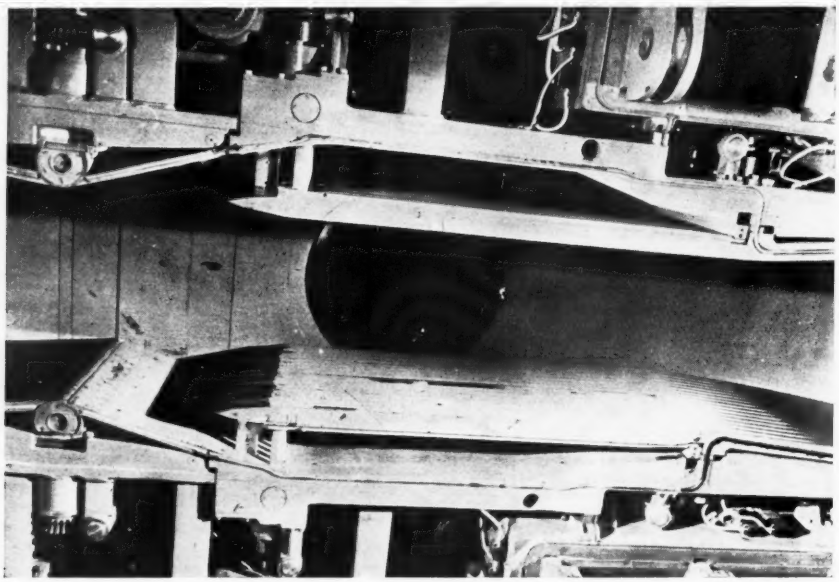

FIGURE 34. Slotted walls in the ballistic wind-tunnel at Flygmotor Aeroengine Company.

number of 0·6 and has a test section of 0·8 m. (2·6 ft.) diameter.

Finally there is a small supersonic tunnel with a test section of 0·023 m.^{2} (6 × 6 in.) (Fig. 33). The Mach number can be varied continuously between 1·5 and 2·8 by means of a single screw mechanism, which in a predetermined manner simultaneously affects the coordinates and derivatives of the inlet and throat curvatures up to the inflection point[38]. The flexible part of the curvature between the inflection point and the test section consists of a spring, with linearly tapering thickness, rigidly clamped at the test section. Due to small curvatures and a suitable choice of the thickness distribution of the flexible part of the wall, a good Mach number distribution (±0·015 or less) has been realised.

An interesting feature of the slotted walls in the ballistic wind tunnel is that the relative slot width can be varied not only in any one cross section but also linearly in the stream direction (Fig. 34). This has proved to be of value for attaining a good pressure distribution at low supersonic speeds. This variability might also be of some advantage in order to approach as closely as possible a complete elimination of the wall interference. Investigations of this kind are exemplified by Fig. 35, which shows the normal force coefficient, the centre of pressure and the drag coefficient for two models (similar to that in Fig. 19) with 1 and 2 per cent. blocking area as functions of the "slot taper ratio" (defined as the relative slot width in per cent. at entrance over the relative slot width at exit) for a Mach number of 0·95. As is seen, the wall interference referred to the drag coefficient is eliminated at a slot taper ratio of 2 to 5·5 per cent. The wall interference in respect of the normal coefficient and the centre of pressure has in this case not been completely eliminated as the curves for the two models do not intersect each other. It might be pointed out, however, that the results shown in this figure are a mere example and that much continued research must be conducted before any definite conclusions can be drawn in respect of all the detailed problems involved.

5.5. BOFORS AERODYNAMIC RESEARCH LABORATORY

This laboratory has recently been established with the main purpose of conducting wind-tunnel experiments as a supplement to firing trials on the proving grounds. Its chief equipment is a compressed air plant and a supersonic blow-down tunnel. The layout of the plant is shown in Fig. 36. This figure also shows the

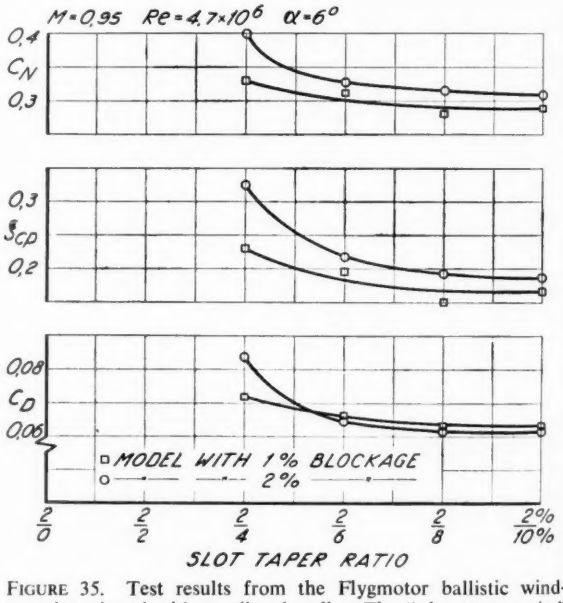

FIGURE 35. Test results from the Flygmotor ballistic wind-tunnel equipped with ventilated walls. The "slot taper ratio" is defined as the relative slot width at entrance over the slot width at exit.

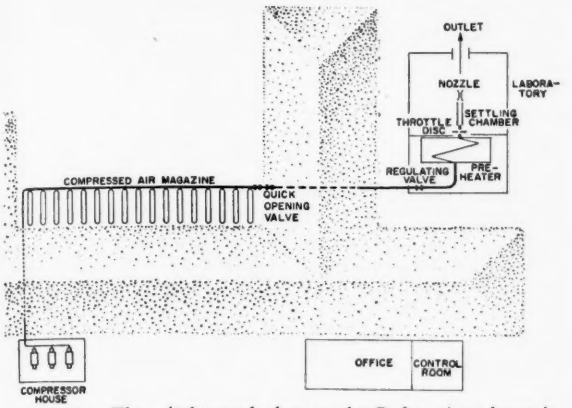

FIGURE 36. The wind-tunnel plant at the Bofors Aerodynamic Research Laboratory.

big sand walls built for safety reasons. The plant is of a rather special type as it is designed to provide test conditions in the tunnel as closely identical with those of actual firing tests as possible. The test section is therefore open to the atmosphere and arrangements are made to achieve atmospheric temperature in the test section by counteracting the adiabatic temperature decrease by means of heating the air before the entrance in the settling chamber.

The compressed air reservoir consists of torpedo air containers of a total volume of 12 m.^{3} (420 ft.^{3}). The containers are charged by compressors of the free piston type to a pressure of 200 atmospheres. After the air has passed a quick-opening valve and then a pressure reduction valve, it is heated in a preheater (Fig. 37). This is constructed of 150 stainless steel tubes which are heated externally by burning propane gas. The pre-heater weighs about 5 tons and the heating capacity is sufficient to keep the temperature of the air (at a maximum pressure of 150 ata (2,130 p.s.i.)) constant at any predetermined value below 650°C. during the test, with an accuracy of ± 5°C. for a test period of 15 sec. and a quantity of air of 75 lb./sec.

The settling chamber, which is also constructed of stainless steel, is insulated and heated electrically in order to prevent the air from the preheater from being cooled before the entrance in the nozzle. Fig. 38 shows the tunnel with a nozzle and a schlieren apparatus. The nozzles are axially symmetrical with the inner diameters at the exit varying from 300 mm. (12 in.) at $M = 1{\cdot}4$ to 120 mm. (4·7 in.) at $M = 3{\cdot}8$.

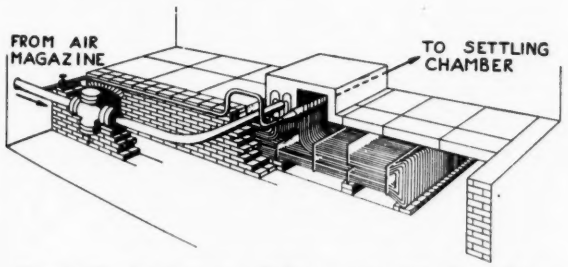

FIGURE 37. Pre-heater at Bofors constructed of stainless steel tubes.

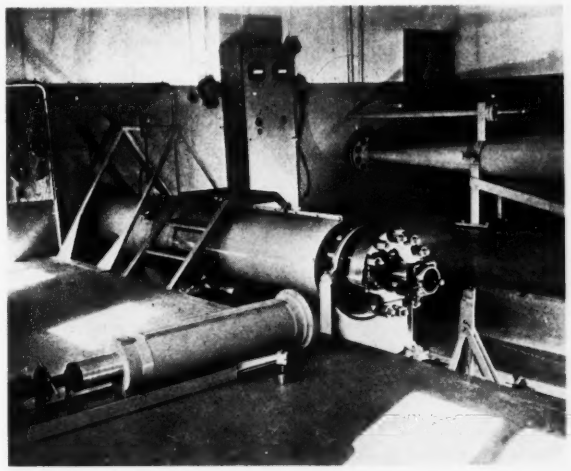

FIGURE 38. Bofors wind-tunnel with open test section.

Figure 39 shows the result of measurements of temperatures at the detonator of a fuse for a Bofors 40 mm. shell. The measurements have been made in such a way that a temperature rise, as a function of time, has been recorded for a number of constant Mach numbers. The temperature has then been calculated as a function of the time of flight.

5.6. A SURVEY OF THE SWEDISH HIGH-SPEED TUNNELS

After the foregoing review of the Swedish high-speed tunnels it might be of some interest to summarise their characteristics in respect of attainable Reynolds numbers and model sizes. This is done in Fig. 40, in which these characteristics are plotted against a background of curves for Reynolds numbers at free flight conditions at a Mach number of 1·0, calculated on a length of 10 m. (32·8 ft.) and for different altitudes. As is seen, all the main Swedish high-speed tunnels fall rather close to a free flight Reynolds number of 20×10^6, corresponding to an altitude of 20,000 m. (66,000 ft.), which means that there is a substantial distance to a free flight

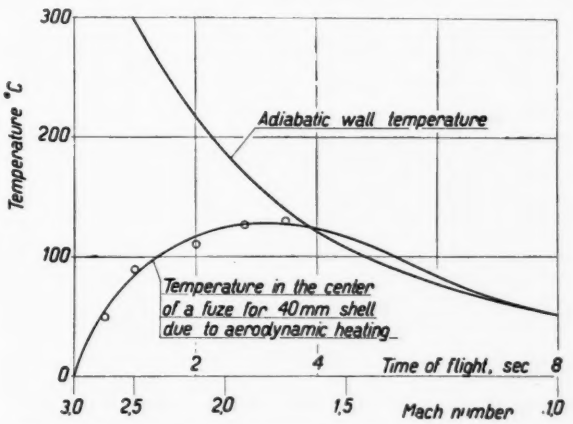

FIGURE 39. Results of measurements of temperatures at the detonator of a fuse for a Bofors 40 mm. shell.

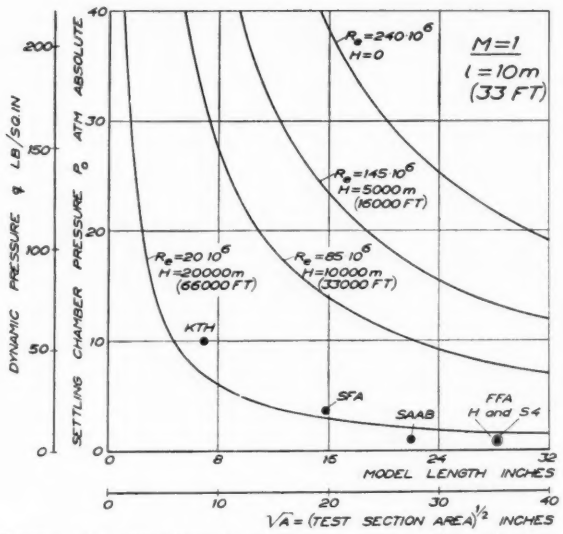

FIGURE 40. Wind-tunnel dimensions and settling chamber pressure for full scale Reynolds number at $M = 1{\cdot}0$.

Reynolds number at ground level or at moderate heights.

Although the problem of simulating free flight conditions in a wind tunnel is by no means solved merely by establishing full-scale Reynolds numbers, we feel that none of our present tunnels is satisfactory from a Reynolds number point of view. We are, however, also aware of the fact that establishing even nearly full-scale Reynolds number in a wind tunnel would be an impossible task to do in Sweden, due in the first place to the high expenditure involved. On account of this we are compelled to arrive at a compromise for a new wind-tunnel design at which a reasonably high Reynolds number is attained with a tunnel size permitting large enough models to be tested. This problem, being by itself a difficult one, is made still more complicated by the fact that a tunnel for supersonic investigations should have arrangements of one kind or another by means of which full-scale conditions in respect of aerodynamic heating and heat transfer can also be simulated.

6. Structural Research Facilities and some Investigations

6.1. THE F.F.A.

The Structures Department of the F.F.A. comprises mainly an experimental hall, a fatigue laboratory and a creep laboratory. The hall is primarily intended for structural testing of complete aeroplanes and large components. It is specially equipped for this purpose with a reinforced floor with recessed steel channels and a reinforced wall with special fixing points, each capable of withstanding a normal force of 30 tons (Fig. 41).

In the field of research and testing concerning *static strength*, substantial efforts have been devoted to tests on simplified specimens representing parts of primary structures. One problem, which has received special attention, is that concerned with the calculation of the critical stress in the compression cover of a number of box beams of various designs subjected to bending loads. This has applications to the type of wing structures in which the stabilisation of the compression cover is mainly achieved by a number of spanwise webs connecting the compression and tension surfaces of the wing, a type of design that has been studied thoroughly at the F.F.A., both experimentally and theoretically[39, 40]. These investigations were, to begin with, confined to the behaviour under pure bending loads, in particular in the range of buckling, of one and multi-cell types of specimens. The method used has been derived from that of moment distribution developed mainly by the N.A.C.A. for several purposes, among others for designing box beams with integral sections and a large number of cells. The work at the F.F.A. has been extended to built-up sections (with rivets and corner extrusions) and the experimental results have shown good agreement with the extended theory.

In later years the behaviour of such beams in the post-buckling range has also been studied. After buckling has occurred, the stress is no longer constant over the width of the compression skin. The stress distribution has for this reason been thoroughly recorded after buckling up to almost complete failure. For the evaluation of the test results the same method of presentation has been used as that applied by the N.A.C.A.[41]. In this representation the average stress of the compression skin at failure, σ_{max}, is related to the buckling stress, σ_{cr}, and plotted versus the ratio σ_{cr}/σ_{cy}, where σ_{cy} is the maximum stress at the corner of the compression skin,

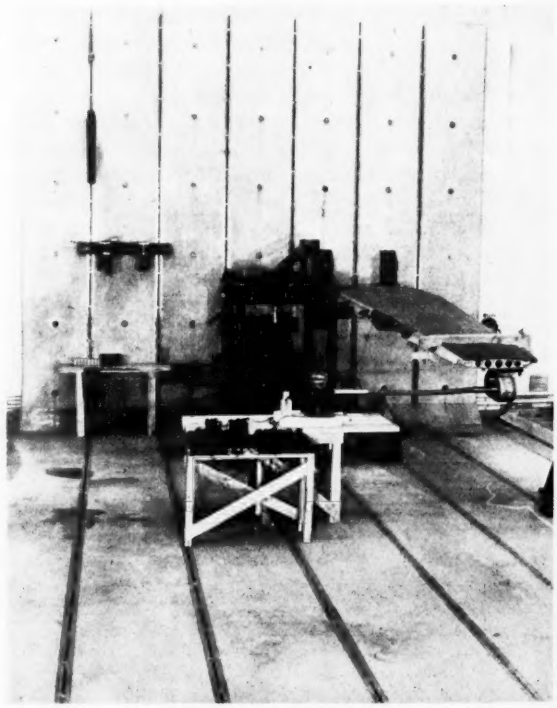

FIGURE 41. A part of the F.F.A. hall for structural tests with reinforced wall and floor.

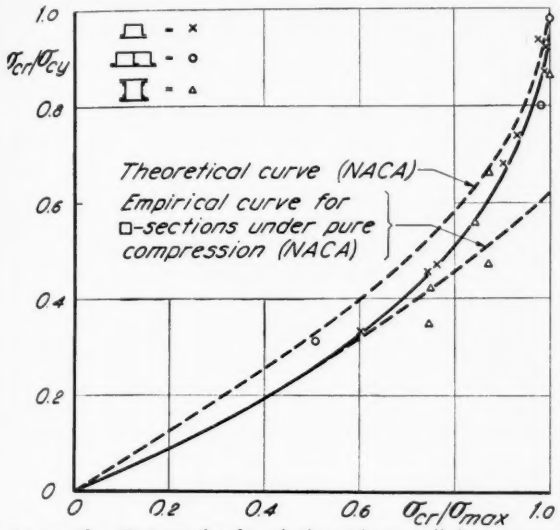

FIGURE 42. Test results for single and two-cell box beams, loaded under pure bending moment. Symbols are explained in the text.

which is usually very close to the yield stress in compression. This is illustrated by Fig. 42, in which our test results for a number of one- and two-cell box beams loaded in pure bending have been plotted, together with the theoretical curve of the N.A.C.A. and the empirical curve obtained by the N.A.C.A. for extruded single-cell square tubes under pure compression. As σ_{cr} can be determined fairly accurately from the methods already referred to, and as σ_{cy} is a quality of the material, it is possible to determine σ_{max} from this type of diagram. After σ_{max} has been determined, the bending moment at failure of the box beam can be calculated by means of simple bending theory, it should only be remembered that the displaced position of the neutral axis, which depends on the ratio of σ_{max}/σ_{cy}, has to be taken into account.

Investigations of this kind have been extended to somewhat modified types of structures, as is exemplified by Fig. 43 showing a thick skin wing section with curved covers and double-web spars.

For the testing of shear webs and similar investigations a special test rig has been constructed (Fig. 44). The test specimen is fixed by means of bolts between two horizontal beams. The top beam is fixed to the rig and the lower one can be displaced horizontally. The load is applied to the lower beam by means of two tension bars and can reach a maximum of 80 tons. With this and another similar rig an extensive series of tests has been carried out, in co-operation with Saab, for the determination of strength and stiffness of shear webs with and without lightening holes and with and without vertical stiffeners[42]. Fig. 45 shows a typical specimen and also illustrates the method of attachment which provides fixity conditions for the web rather similar to reality, as the web is supported by portions of the upper and lower skin into which the loads are introduced. This study has dealt with various combinations of different geometrical properties such as the web thickness, t, and height, h. In Fig. 46 some of our results are plotted in a way suitable for the designer.

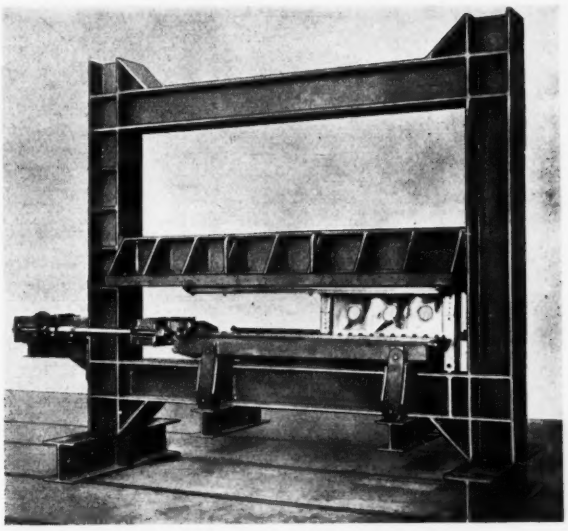

FIGURE 44. Rig for testing shear webs.

The efficient design of swept-back and delta wings calls for thorough investigations into their structural behaviour. To supplement the theoretical estimation of the stress distribution and deflection patterns, some model wings manufactured mainly in Perspex have been tested at the F.F.A. A review of these models, the testing techniques that have been used and the most important results obtained, has been described in Ref. 43

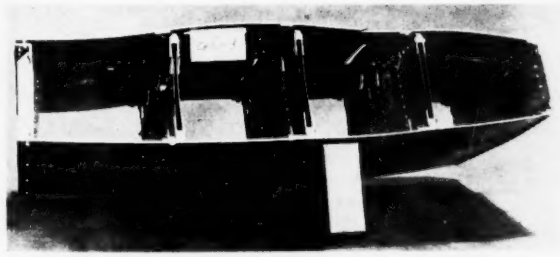

FIGURE 43. Section of a tested four-cell wing.

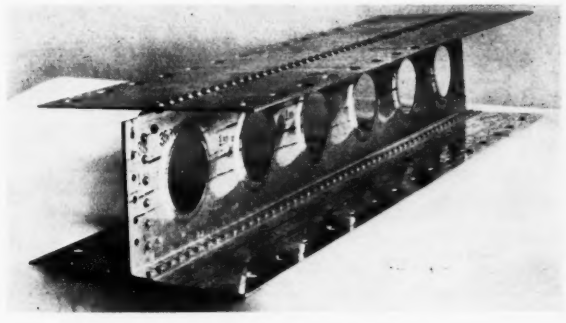

FIGURE 45. Typical shear test specimen.

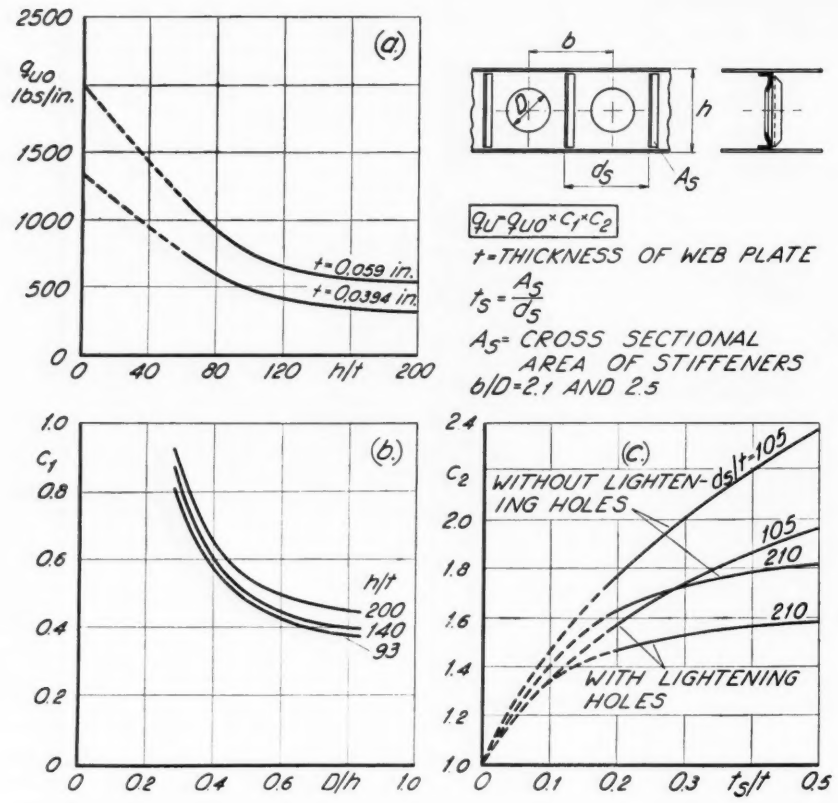

FIGURE 46. Chart based on experiments for the design of webs. The ultimate shear flow, q_u, for web with lightening holes and stiffeners is equal to $q_{uo} \times C_1 \times C_2$, where: q_{uo}, the ultimate shear flow, for a plain web (Fig. (*a*)); C_1, the correction factor for webs with lightening holes (Fig. (*b*)); C_2, the correction factor for webs with stiffeners (Fig. (*c*)). Note: Figs. (*b*) and (*c*) apply for ratios of b/D from 2·1 to 2·5.

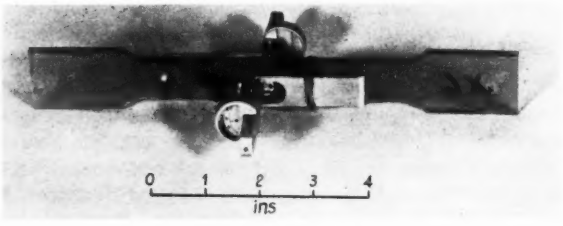

FIGURE 47. Two C.E.-Johansson extensometers mounted for tests on a Perspex specimen.

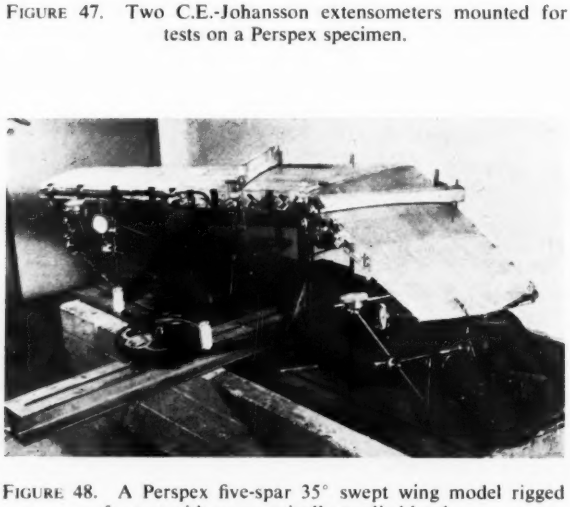

FIGURE 48. A Perspex five-spar 35° swept wing model rigged for test with symmetrically applied loads.

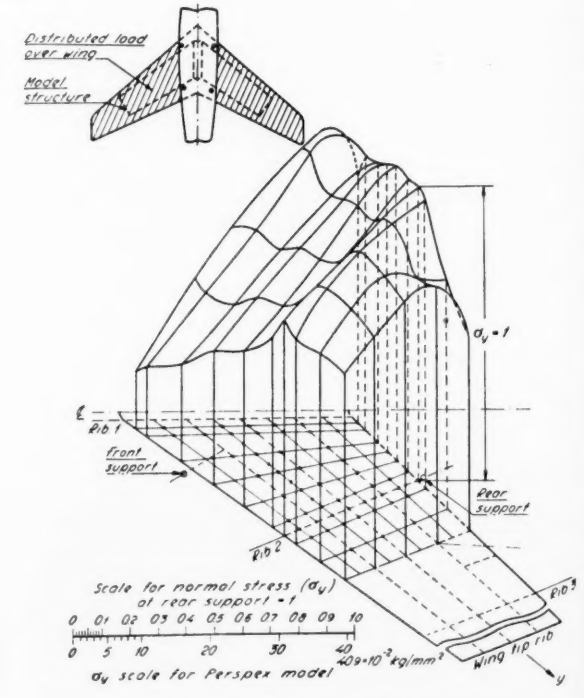

FIGURE 49. Illustration of the compressive stresses over the top surface of the Perspex model (Fig. 48) due to design case loads.

and therefore only a few aspects of this work are presented here.

When conducting experimental investigations on plastic models, it has been found that mechanical precision extensometers made by the Swedish firm C. E.-Johansson have been particularly suited for this purpose. One type of these instruments (Fig. 47) has a gauge length which ranges from about 0·1 to 0·4 in. It has been used with great success both for the determination of the mechanical properties of thin coupons of Perspex and for static tests on complete Perspex models. For these purposes most other types of mechanical or electrical strain gauges give uncertain results for a number of reasons. It might, for instance, be pointed out that wire resistance strain gauges are not suitable because of the effect of the cement on the properties of the Perspex and the stiffening effect of the gauge on the measuring surface.

When testing plastic models the difficulties due to creep must be overcome. For this reason we have applied a fixed deflection to the model instead of a constant load. This implies that the applied load decreases with time, but this can be taken into account by allowing the same time to elapse when determining the applied loads on the model and the modulus of elasticity derived from tests on material coupons.

One of the Perspex models which has been investigated at the F.F.A. is shown in Fig. 48[44]. This is a five spar wing with top and bottom skins of tapered thickness and four ribs in each half of the model located perpendicular to the rear spar. The model was supported at four points representing the wing and fuselage attachments. To apply the vertical loads, two screw jacks were used.

The purpose of this investigation was mainly to determine the principal stresses and their directions at about eighty points on the top surface of the port half for a realistic design case (maximum normal acceleration). For this purpose the method of unit loads was adopted. Besides the normal advantage of this method of being readily applicable for the determination of the stress distribution at any external loading pattern, it is particularly suitable for model testing, firstly because the surface is not restricted by lots of loading levers and secondly, because loading by levers would be particularly inconvenient when applying a constant deformation. The stress distribution was thus determined for five consecutive tests where two loads were applied symmetrically, one on each half of the model in each test. The results, reduced to unit loads, were then factored to correspond to the design case and thereafter superimposed. The result of the investigation is illustrated by Fig. 49.

Static model tests have also been made with a wing model built of aluminium alloy[45]. This model (Fig. 50) is an idealised swept-back, multi-cell wing with an angle of sweep of 30° and supported at two points along the centre-line. In order to obtain a homogeneous structure without the stress concentrations normally associated with rivets and bolts, the parts of the model were joined by Araldite and Redux adhesives. The strains were measured by F.F.A. electrical resistance

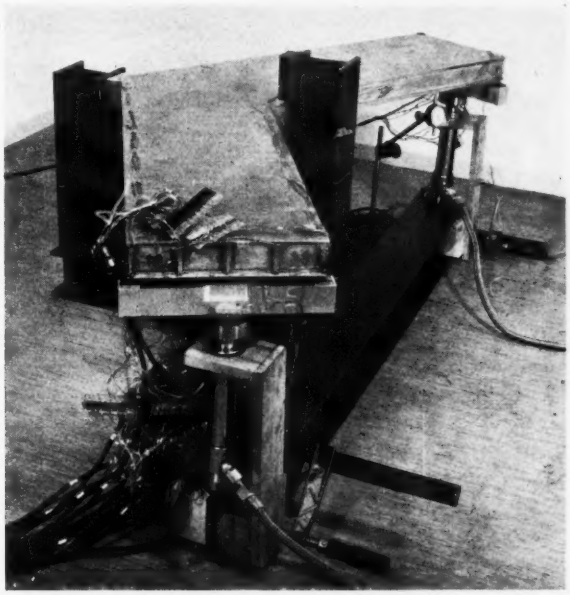

FIGURE 50. The bending test set-up for a multi-spar aluminium alloy 30° swept wing.

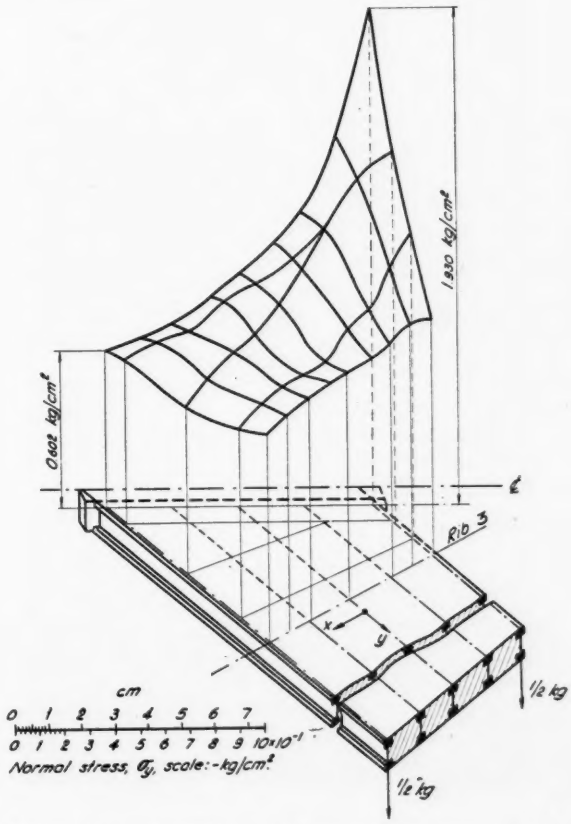

FIGURE 51. Illustration of the compressive stresses in the aluminium alloy model (Fig. 50).

strain gauges arranged in three-gauge rosettes. Symmetrical loading was applied to the model wing for two loading cases, one with loads applied at the tip ribs on both the front and the rear spars and one with the loads applied at the tip rib on the rear spar only. The result of the first mentioned loading case is shown in Fig. 51.

The experimental results have been compared with strain energy calculations[46]. Good agreement concerning the normal stresses was obtained, while for the shear stresses certain discrepancies were observed between the theoretical and the experimental results.

The Structures Department has also been concerned with sandwich panels with honeycomb cores in pure aluminium[47]. The cores which have so far received attention, have been of the hexagonal "expanded" type in 2S-H material. The maximum inscribed circle of the cells ranged from $\frac{1}{4}$ to $\frac{1}{2}$ in. diameter and the foil thickness ranged from 0·0015 to 0·0025 in. The rather new Redux 775 R film was used for bonding cover skins to honeycomb cores. Among several studies, we have tested approximately 70 short columns with various combinations of core size, cover skin materials and cover skin thickness, and the results for the ultimate stresses based on the area of the cover skins, averaged the rather high value of 44 kg./mm.^{2} (64,000 lb./in.^{2}) for 1·0 m. thick 75S-T covers. The total thickness of the columns was 32 mm. (1·26 in.) and their length was 150 mm. (6 in.). Several typical failures with these columns are shown in Fig. 52. It should be noted that the ends of the specimens were cast in Wood's metal to avoid any premature failures (these ends have been sawn off before the photograph was taken). The stresses were consistently free from the excessive scatter normally associated with such tests.

FIGURE 52. Some typical failures from compressive tests on short sandwich columns with aluminium honeycomb cores of the expanded type.

For *testing undercarriages* a special drop rig has been built (Fig. 53). It has a maximum drop height of 14 ft. and a maximum impact load of 40 tons. To simulate the "spin-up" loads which occur during the landing of aeroplanes the wheel is spun up, before the drop, to a peripherical speed equivalent to the landing speed of the aeroplane. By means of a specially designed "gauge table" the vertical and horizontal forces are measured upon impact of the wheel (Fig. 54). This gauge table comprises a top plate supported by four strain-gauged legs for the determination of the vertical component of the load, P_z, and the two horizontal components, P_y and P_x. In this drop hammer the landing gears of all aeroplanes designed in Sweden since the erection of the

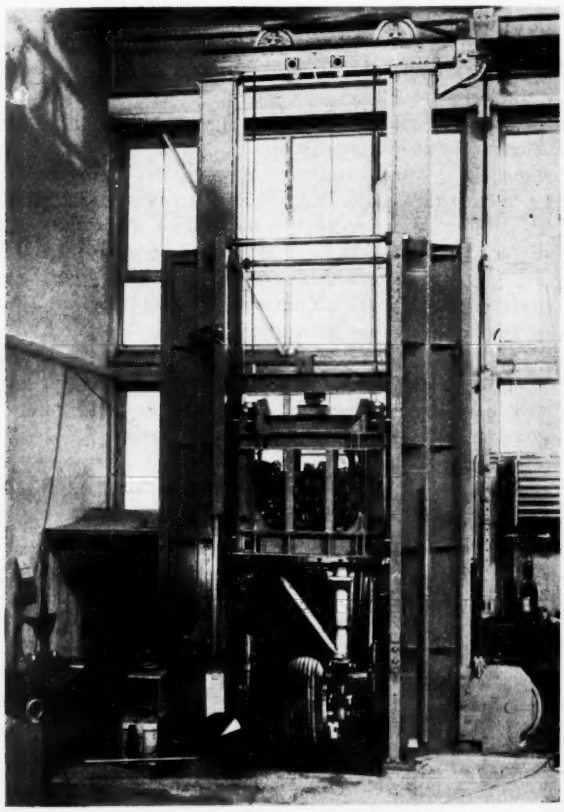

FIGURE 53. The F.F.A. drop-test rig.

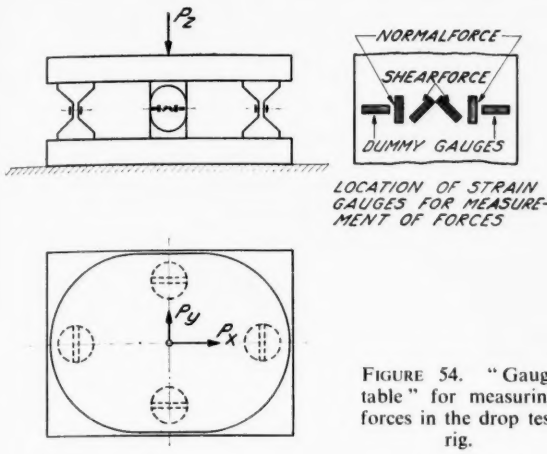

FIGURE 54. "Gauge table" for measuring forces in the drop test rig.

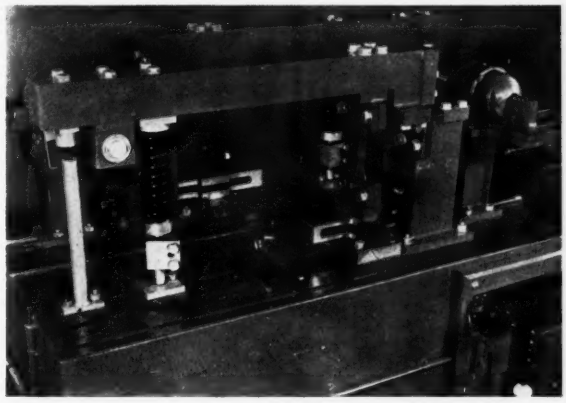

FIGURE 55. Two F.F.A. axial-load fatigue testing machines of 2-ton capacity.

F.F.A. have been tested and a considerable amount of research and development work has been conducted to attain desired qualities of the landing gears.

Since the inception of the F.F.A. the Structures Department has devoted a substantial part of its capacity to the problems of *fatigue of aeroplane structures*. At present the fatigue laboratory comprises more than 20 fatigue testing machines, of which the following types for axial loading (tension and compression) might be mentioned:

Vibrating beam machines of F.F.A. design with a maximum load of 2 tons and with a frequency of about 2,000 cycles/min. (Fig. 55), mechanically-operated 4 ton machines driven by a crank and an electric motor, which can also be operated by hand when only a few load cycles are to be applied; Schenck pulsators of 6 and 20 ton capacity and with a frequency of 2,000 cycles/min., a 10 ton Amsler high-frequency pulsator with a frequency of 9,000-18,000 cycles/min., and a 30 ton Losenhausen hydraulic machine with a frequency of 330-1,000 cycles/min.

One of the 6 ton Schenck machines and the 20 ton Schenck machine are equipped with a special arrangement in order to permit very low frequencies, of the order of 20-30 cycles/min., which are of importance for tests with varying amplitudes (programme-testing). In order to further facilitate this type of testing, these two machines and a few of the others have additional equipment for automatic stopping after a certain predetermined number of load cycles of a certain amplitude.

Our experimental studies on fatigue have mostly dealt with the testing of small specimens representing typical elements in aircraft primary structures in order to establish design information as well as for pure research purposes. The results have been published in a number of reports, for example Refs. 48-50. Tests with varying amplitudes with load spectra representative of load patterns in actual flight have also been one of the main subjects for our research. In recent years rather extensive studies have been made of the abundant scatter so typical for all fatigue results (*see* for example Refs. 51 and 52).

A rather comprehensive survey of the whole problem of fatigue in aeroplane structures has recently been made[53]. In this paper the outline of a general policy for the treatment of this problem has been drawn up, which is to a large extent based on statistical analysis. It has been proposed that a maximum (critical) value of the average failure rate, defined as the ratio between the probability of a catastrophic failure and the "limit" fatigue life corresponding to the same probability level, should be the basis for the said policy and methods of statistical analysis. The numerical value of such a critical failure rate should, if possible, be agreed upon internationally, but a preliminary suggestion is that all transport aeroplanes should be designed so that the failure rate does not exceed a value of one in 10^9 hours.

In the same paper[53] a study has also been made of the relationship between such a failure rate criterion and fatigue factors of safety based either on load, or on time, as is illustrated in Figs. 56 and 57. Fig. 56, which is valid for statically determinate wing structures of transport aeroplanes, shows the increase in structural area (on top of that needed for adequate static strength) necessary to attain a certain limit life with a certain probability as governed by the failure rate criterion (F_{cr}). Up to a certain life, (T_s), no increase of area ($k_A = 1$) is needed, but then the curve goes upward rather rapidly and cuts a number of somewhat more inclined curves for constant probability of failure. The only reasonable way of defining factors of safety is, as the ratio between points on this curve and corresponding points on the curve for 50 per cent. probability of failure. It is obvious that such a factor, be it defined on load or on time, will vary with the life of the structure. This variation with life could, however, be tolerated, if only one type of construction is considered, but a more serious disadvantage with the use of generally prescribed factors of safety in respect of fatigue is that the magnitude of the factors will necessarily differ considerably for different types of design and for different materials. This is illustrated by comparing Fig. 56 with Fig. 57, which shows schematically the case for a redundant wing structure. The greatly decreased probability of a

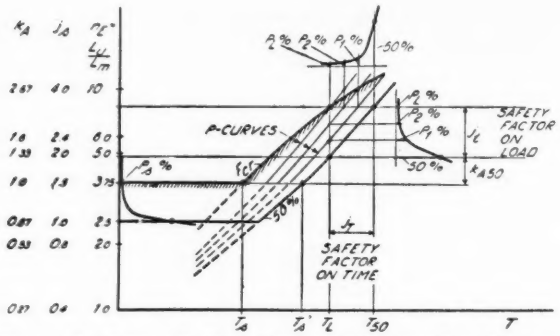

FIGURE 56. Schematic illustration of static strength and factors of safety for fatigue, for a statically determinate structure with one fatigue-sensitive element.

catastrophic failure with a redundant structure brings the two curves for 50 per cent. probability and for the failure rate much closer together, which implies that considerably smaller factors of safety are necessary to provide the same critical failure rate, *i.e.* the same level of safety, for the entire aeroplane of the redundant type as compared with the statically determinate one.

It might be emphasised at this point that, while a specified maximum value of the critical failure rate, of for example 10^{-9}, should be the joint general goal or requirement to aim at, various methods of calculation and testing should be accepted for proving compliance with such a general requirement. Thus, a complete statistical analysis should not necessarily be called for. One conceivable method of compliance would be to apply different factors of safety (on load or on life) for different types of construction, and these factors should be of such a magnitude that, by means of general studies, they can be shown to provide the required safety for designs

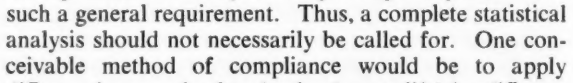

FIGURE 58. P-s-N^{-c} diagram for 75S-T notched specimens subjected to fluctuating tensile loads with lower load limit equal to zero ($S_u = 94{,}160$ p.s.i.).

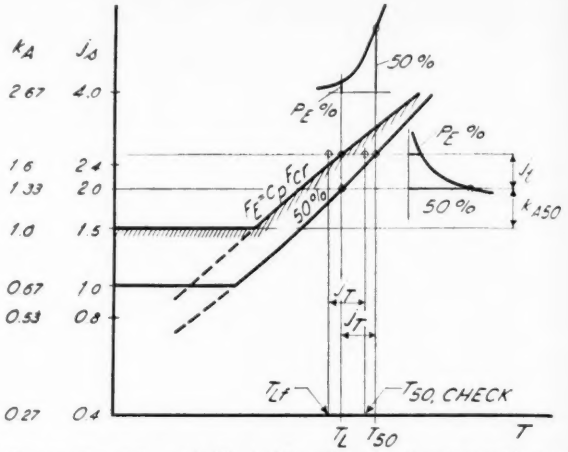

FIGURE 57. Schematic illustration of static strength and factors of safety for fatigue, for an element in a redundant structure.

belonging to a certain type of construction (in respect of redundancy, detailed design and material, and so on). Another method of compliance would be to use, throughout the entire primary structure, such a high degree of redundancy or "fail-safe" design that the structure, without statistical analysis, can be deemed with certainty to provide a higher level of safety than the minimum required. A third method of compliance (which is likely to provide the minimum weight) is, of course, a complete, or nearly complete, statistical analysis, whereby appropriate conservative assumptions should be made at each point of the analysis where a statistical treatment is difficult at the current level of knowledge.

In Ref. 53 an account has also been made of recent theoretical and experimental investigations in fatigue. An explicit formula based on the cumulative damage theory has been derived for the calculation of the fatigue life for wing structures subjected to loads of any given spectrum following a certain common type. With this formula the hitherto usual method of numerical integration is avoided and it has been possible to establish a number of convenient design charts of a general nature.

As an example of the experimental results and some methods of their evaluation, Fig. 58 shows the result of fatigue tests with nearly 400 notched specimens in 75S-T (corresponding to D.T.D. 546) of 10 mm. (0·39 in.) diameter circular cross section and notched by a 3 mm. (0·12 in.) drilled hole. In this plot the normal presentation of endurance curves has been replaced by using as abscissa the quantity N^{-c}, where N is the number of load cycles and c is one of the parameters in the S-N equation defined in the figure. This exemplifies the rather comprehensive study that has been made concerning the variation of the scatter characteristics with the load and the number of load cycles, a matter for which this type of diagram is particularly suitable.

Some recent investigations on varying amplitude loading or programme testing might also be mentioned here and some results are presented in Fig. 59. The test specimens, which were of the same geometry and were

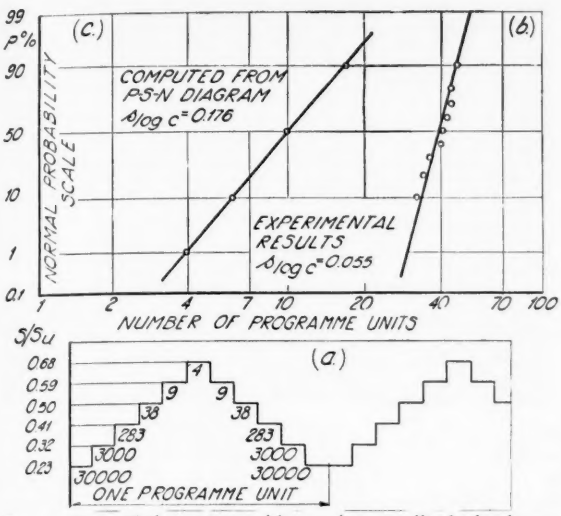

FIGURE 59. Fatigue tests with varying amplitude loads on 75S-T notched specimens: (*a*) Spectrum of loads applied; (*b*) Test results; (*c*) Life calculated from *S-N* tests corresponding to Fig. 58.

taken from the same batch of 75S-T material already mentioned, were subjected to loads of a spectrum shown in Fig. 59(*a*). The test values for the various life-times in number of programme units, are plotted on a normal (Gaussian) probability graph paper in Fig. 59(*b*). A comparative plot has also been made in Fig. 59(*c*) for the life as calculated from the *S-N* tests referred to previously. For these calculations the usual cumulative damage theory has been applied. A comparison between the two curves (*b*) and (*c*) shows firstly, that on the average the life-time as obtained by programme testing is almost four times longer* than that based on *S-N* testing and cumulative damage calculations, and secondly, that the standard deviation (which corresponds to the slope of the curves) is about three times larger for the *S-N* results than for the programme test results. Interesting as these two observations are, great caution must be taken not to draw too far-reaching conclusions from the comparison. It might thus be pointed out that the increase in life with programme testing is probably due, to a large extent, to the very high loads included in each loading cycle, which cause a levelling-out of the stress concentration at the notch, resulting in a beneficial residual compressive stress. An additional explanation for the long life is probably also that no compressive stresses were included in the loading cycle, which implies that the load spectrum is not typical for the most usual type of load patterns for aeroplane structures. Concerning the difference in scatter (standard deviation) this investigation confirms similar observations made elsewhere. The observed decrease in scatter with programme testing is undoubtedly of great importance and constitutes a certain advantage with this type of testing. It might be emphasised, however, that this reduced scatter is not by itself a reason for the

*In error the factor was given as seven in the verbal presentation.

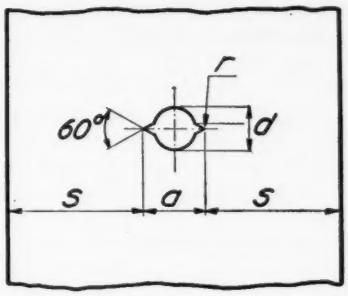

FIGURE 60. Plate specimen used for studies concerning crack propagation. The values of *a*, *d*, *r* and *s* have been varied.

replacement of *S-N* testing by programme testing, as the *S-N* method must still be considered to be the main basis for establishing the pure fatigue qualities of materials and structural elements, whereas all kinds of varying amplitude testing give a mixture of these qualities with particular spectra of applied loads. The natural conclusion to be drawn is that both types of testing have their place and that a substantial amount of theoretical and experimental research is needed to co-ordinate results from the two methods and hence, increase our knowledge of the fatigue problem.

The important problem of crack propagation is also being studied at the F.F.A. in co-operation with Saab. In order to study this phenomenon some special test specimens have been designed (Fig. 60), in which the time for the crack propagation constitutes a considerable part of the whole life-time. Although these investigations are not yet completed, the results obtained so far indicate, firstly, that there is an exponential relationship between the rate of crack propagation and the average stress on the remaining structural area, and secondly, that this rate of propagation is independent of the length of the crack, provided that the average stress is kept constant. A third observation which might prove to be of fundamental importance is that the time for a certain percentage growth of the crack for geometrically congruent specimens of different sizes is independent of the absolute size. This means, for example, that the rate of crack propagation expressed in length of crack divided by number of load cycles, is twice as large if the size of the specimen is doubled, provided that the average stress on the remaining area is the same. A first report of these investigations has been published[54].

We have been working for a long time on various methods of recording the varying loads to which aeroplane structures are subjected. The main object of this activity has been to design pieces of equipment with which the fatigue damage in any individual aeroplane structure can be determined, and we have refrained from attempts to accumulate statistical data of atmospheric gust conditions and the like. A brief survey of this activity is given in Ref. 53. It might only be mentioned here that a counting accelerometer was designed at the F.F.A. in 1942. More recent efforts on fatigue meters have been devoted to the development of a purely mechanical strain actuated fatigue counter (Fig. 61). This strain counter, which counts a number of strains of different levels, should preferably not be mounted in a fatigue-sensitive part of the structure, but

on a portion of the structure, the strains of which are proportional to those affecting the fatigue-sensitive part.

Another fatigue meter, the so-called "Fatigue Clock," is also under development. In this device the counting of the strains at different levels is replaced by an integration of the corresponding fatigue damage. This is accomplished in such a way that the accumulated damage, expressed for instance in the percentage consumption of the limit fatigue life, is read off directly from one single dial.

In the field of structural research with dynamic loading we have also made numerous investigations concerning the growth of play, for example, in bearings and bushes. For this purpose a special machine has been developed (Fig. 62). The load on the specimen is obtained by two contra-rotating eccentric masses which are mounted in a spring-supported housing. A maximum load amplitude of 3·5 tons can be obtained and the frequency can be regulated between 900 and 2,000 cycles per minute. The load on the test specimen (B) is measured with a strain gauge (G) and an oscillograph. When the play between the two bearing surfaces is zero, the load varies approximately according to a sine wave, but with increasing play impact forces occur between the two surfaces and the course of the loading is distorted.

In recent years we have naturally been confronted with the complicated and important *structural problems caused by aerodynamic heating* of high-speed aeroplanes. This phenomenon certainly opens up such an enormous field of structural research and development that it is no exaggeration to state that the need for structural research has been multiplied many times. In view of our limited research capacity we obviously cannot deal with all aspects of these problems. Thus, for the time being we have to restrict ourselves to some limited efforts, and in order to make them as fruitful as possible, we have selected some problems which are of immediate practical significance and at the same time give us opportunities to develop the specialised techniques required for investigations of this kind, thus putting us in a favourable position to conduct fundamental research also in this field.

One series of tests (Fig. 63) is aimed at the simulation of kinetic heating of a wing panel simultaneously subjected to compressive end loads and loads normal to the surface. To achieve this, the test specimen is incorporated as the upper panel of a box beam which is subjected to a constant bending moment giving compression in the test specimen. The normal forces on the test specimen are applied by a water bag inside the beam. Heating is applied by a battery of infra-red tubular heaters of a total power of 50 kW. As shown in the figure, the battery is mounted on a movable frame which can be quickly rotated downwards in order to apply the heating to correspond with certain realistic conditions in actual flight. The rate of heating in this particular case was 5°F. per sec. In order to increase the absorption capacity of the panel, the surface was sprayed with black paint, and the thickness of the paint was varied over the surface to provide a uniform temperature distribution over the surface. Since these tests

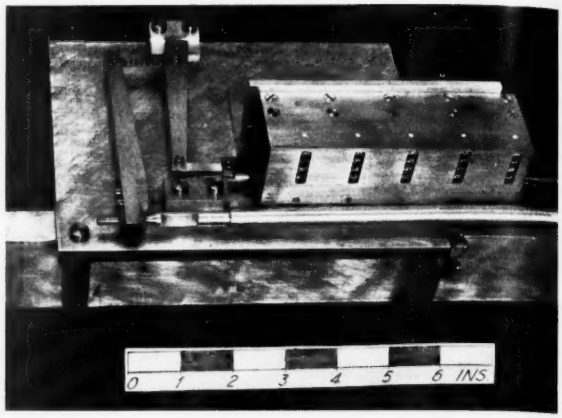

FIGURE 61. The F.F.A. "Strain Counter."

were completed the Philips Company in Holland has introduced on the market a new type of quartz tubular heater by which rapid application of heating can be accomplished without using the described movable frame-work.

A special apparatus has also been designed to study the influence of repeated heating on the mechanical properties of materials, which at the same time are being subjected to either constant or varying tensile loads.

For normal creep testing we have a number of creep test machines capable of operating at temperatures up to 1,000°C. Moreover we have special equipment for applying heat in combination with both static and fatigue testing.

6.2. THE K.T.H.

The Division of Aeroplane Structures at the Royal Institute of Technology, besides its normal education activity, has mainly been concerned with structural

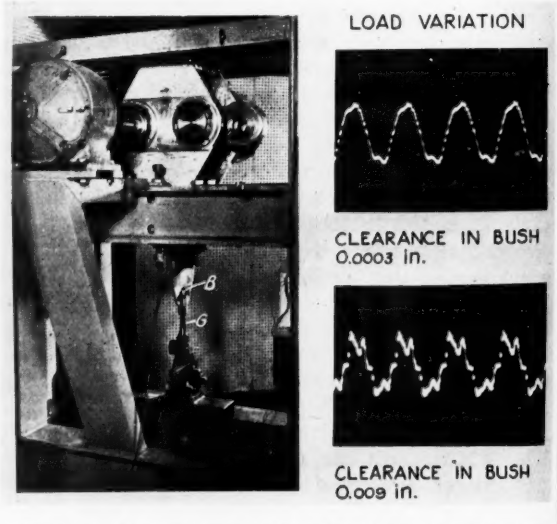

FIGURE 62. Machine for studying effect of play in various types of bearings and bushes.

research aiming at the determination of stress distributions in modern wing structures. Lack of facilities has limited the amount of experimental work and this is why the efforts have mainly been devoted to theoretical studies. These studies have been concerned particularly with the determination of stress distributions in highly redundant structures[55, 56]. Such studies have also been supported by the electrical analogy method. The experimental investigations have mainly been confined to tests with structural models in Plexiglas, for example, of a model of a delta wing combined with a part of the fuselage. In addition photoelastic stress analysis of structural components has been conducted in co-operation with another department at the K.T.H.

6.3. SAAB AIRCRAFT COMPANY

The structural research needed to establish design information for new types of aircraft is naturally often initiated at Saab and conducted partly at Saab and, to a large extent, at the F.F.A. and the K.T.H. as a result of close co-operation. The following are examples of the activity of Saab in the structural field.

Saab is intimately concerned with the problem of developing materials that are suitable for use at elevated temperatures such as those caused by kinetic heating. One such problem is to investigate the temperature limits for economic structural application of light materials, especially 24S, and also for some new aluminium alloys.

Plastic materials for high speed flight are also being studied. Acrylic plastics for transparent canopies have been evaluated for the maximum allowable outside temperature in thermal flight conditions, when the inside of the acrylic is kept at a lower temperature than the outside. New design strength data have been obtained with a specially developed apparatus for simulating such thermal flight conditions.

Furthermore, Saab is considering the use of heat resistant reinforced plastics for future high-speed aeroplanes, not only as enclosures for electronic equipment, but also as substitutes for metals in the aerodynamically heated shell structure, especially in parts where shear stiffness requirements are not prevalent, for example in the fuselage structure. In order to study the suitability of various reinforced plastics for such applications, a test programme is being carried out at the F.F.A. incorporating curved integrally stiffened fuselage panels, subjected to shear loading and external heating, and simulating thermal flight conditions for piloted aircraft.

Adhesive bonding of aircraft structures has for some time been gradually introduced in Saab's aircraft designs. Parallel with the introduction of this production method, metal bonding is to a large extent concentrated on developing design criteria for adhesive joints in aircraft.

In the field of fatigue, one investigation might be mentioned, namely, the fatigue testing at one constant amplitude level of about 1,000 nominally identical 24S-T notched specimens[57]. The particular object of this study was to improve our knowledge of the scatter characteristics of an element typical for current designs. It was found that the shortest life-time was only $\frac{1}{5}$ of the mean value. A few other contributions in this field have been published in Refs. 58 and 59.

It might finally be mentioned that the activity at Saab for rapid numerical computation is very advanced. Modern mathematical punched card machines of the American I.B.M. electronic types are being used extensively and a new electronic calculating machine of Swedish design "BESK" (Binär Elektronisk Siffer Kalkulator) has been ordered from the Swedish Government's Board for Mathematical Machines. The I.B.M. machines are being used for a number of different types of calculations. Problems concerned with statically indeterminate structures are an example. The number of redundancies can be very large and problems with less than a hundred redundancies give no serious difficulties. Further information about this activity can be obtained from the series of reports in Ref. 60.

7. Research in Measurement Techniques at the F.F.A.

Highly developed measurement equipment and techniques are of the utmost importance for modern

FIGURE 63. Loading rig and arrangement of infra-red tubular heaters for testing a wing panel under the influence of heat.

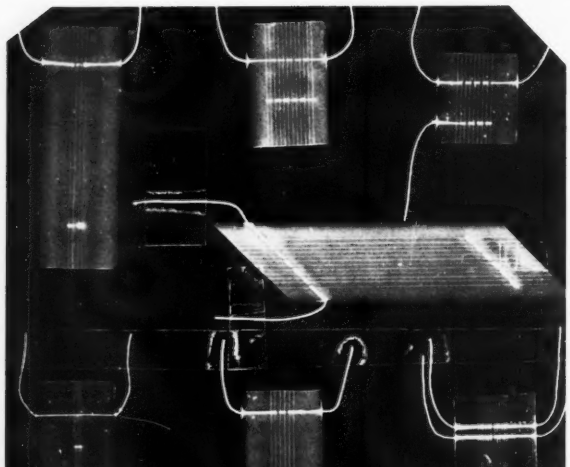

FIGURE 64. Different types of F.F.A. strain gauges.

experimental research. For this reason a special Physics Department was formed at the inception of the F.F.A. This department, in the first place, assists the three other technical departments of the F.F.A. in solving their measurement problems; secondly, it conducts independent research on measurement techniques and this activity is considered of great importance in order to keep in the forefront of the rapid development in this field. In the following a few pieces of measurement equipment developed at the F.F.A. will be described briefly.

In 1945 it was found that the available paper-based wire resistance strain gauges were unsuitable for many purposes because of, for example, their sensitivity to humidity. On account of this a new type of electric strain gauge was developed in which the wires were fully embedded in non-hygroscopic plastic material. Fig. 64 shows a few examples of the F.F.A. gauges designed for different applications. Small gauges, down to a size of about $1{\cdot}5 \times 3$ mm. ($0{\cdot}06 \times 0{\cdot}12$ in.) have been produced. Further information about these gauges can be obtained from Refs. 61 and 62.

Since 1953 activity in this field has, to a large extent, been devoted to the development of heat resistant strain gauges and some gauges are capable of resisting, with reasonable accuracy, temperatures up to 300°C. Furthermore combined gauges have been produced for measuring both strains and temperatures simultaneously and at the same spot, which is of great importance for structural research at elevated temperatures, in particular at varying temperature conditions.

For measuring accurately the loads and strains at dynamic loadings, particularly in connection with fatigue tests, a special instrument has been developed which can be used for the determination of both static and dynamic loads and strains (Fig. 65). The pick-up consists of a d.c.-fed strain-gauge bridge located on the test specimen, or on a calibrated spring coupled in series with the specimen. The bridge is balanced by means of an accurately calibrated potentiometer, the reading from which is a measure of the strain. The principle of operation is based on the idea of short-circuiting the output of the bridge except for short time intervals (Fig. 65(*a*)). If the bridge is not balanced during these intervals, a signal will appear which is amplified and displayed on a cathode-ray tube. By adjusting the balancing potentiometer the output of the bridge during the selected intervals can be made to coincide with the abscissa which corresponds to the short-circuited bridge (Fig. 65(*b*)). When the test specimen is subjected to a pulsating load, the shortening switch and the tube sweep have to be synchronised with the oscillation in order to obtain a stationary figure on the tube screen. By opening the circuit on the crest and trough value of a cycle, and balancing the bridge to zero during these moments, potentiometer readings are obtained which can be compared with static calibration readings.

The advantages of this principle are that d.c.-amplifiers can be avoided and that an enlarged view of the selected part of the curve yielding a high degree of accuracy is easily obtained. In fact, the accuracy is normally better than 10^{-6} in strain and is limited mainly by the calibration achieved with the pick-up.

The apparatus contains one high-gain a.c.-amplifier for the signal, another for timing purposes and also, trigger and sweep circuits. The speed of the latter is automatically governed by the fatigue machine. The frequency range of the apparatus is 1 to 300 cycles/sec. One apparatus will be sufficient for serving a number of fatigue testing machines by switching and successively measuring. A report on this apparatus is being prepared.

The "Dampometer," which was referred to in Section 5.1.2, has been developed by the Physics and the Aerodynamics Departments in co-operation. It is based on the principle of representing the damped oscillation by a rotating vector on the screen of a cathode ray tube, the rate of decrease of the length of the vector constituting a measure of the damping (Fig. 66). The screen of the tube is covered by a circular disc with a number of equally spaced radial slots, as seen in the

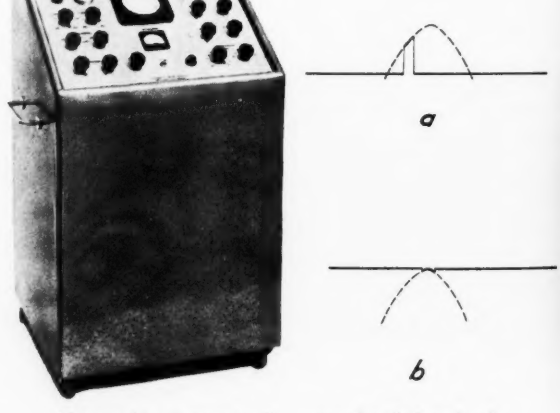

FIGURE 65. Apparatus for measuring fatigue loads.

figure. While the spot moves on the spiral, it passes the slots in the screen cover and thus gives light pulses to a photo-cell. The number of pulses produced by the cathode ray, while the radius vector of the spiral decreases from the outer to the inner radius of the slots, is registered on an electronic counter, which gives the number directly in decimal digits. The logarithmic decrement of the oscillation is inversely proportional to this number. This apparatus has proved to be very satisfactory and its application is not limited to investigations in wind tunnels, as it can be used for all kinds of tests where damped oscillations have to be studied.

Another apparatus, which has been developed in co-operation with the Aerodynamics Department, is a device for semi-automatic transforming of pressure measurement and other length-represented data to punched cards and diagrams (Fig. 67). The purpose of the apparatus is to reduce the tedious work usually involved when analysing measurements recorded on film or paper tape. The apparatus consists of three major parts, *i.e.* the enlarging apparatus, the decimal transforming device and the plotting device. Data, recorded as characteristic lengths on film or paper tape, are projected upon a paper-covered plate. This plate is movable along one axis (position of measuring points along wing) and above the plate a pointer can be positioned in an orthogonal direction (values of pressure measurements). The position of the pointer is registered by a sliding contact on a segment line, representing decimal positions. By means of electrical circuits between the segments, and a punching machine, the position of each segment is transformed into decimals in a punched card. The pointer is mechanically coupled to a device which plots the data on the diagram simultaneously with the decimal transformation. The speed of evaluation is about 30 points per minute.

Besides the equipment already described the Physics Department has developed a number of other measurement instruments, for example highly sensitive measuring bridges which are uninfluenced by the large variations in the lengths of the leads to the pick-ups, amplifiers for various purposes, a four-channel cathode ray recorder, light electric counters suitable, for example, for counting accelerometers, a special transformer for transforming a.c. current into a stable d.c. current of low voltage, and so on; most of these instruments have been in use for a considerable time. The Physics Department has also devoted a substantial part of its activity to the development of internal balances with strain gauges both of bonded and of unbonded types for wind tunnel investigations.

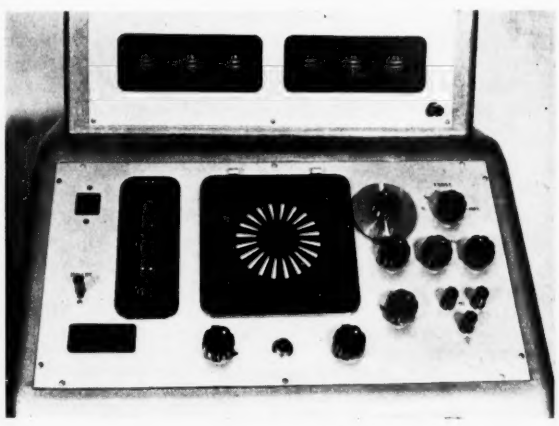

FIGURE 66. The " Dampometer."

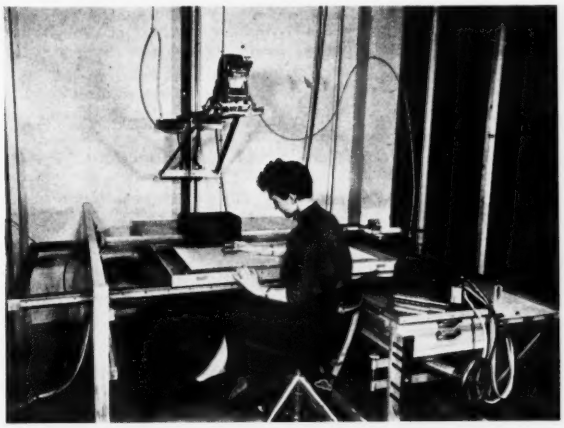

FIGURE 67. Apparatus for transforming pressure data from manometers to punched cards.

8. Acknowledgments

I wish to express my great appreciation to my colleagues within and outside the F.F.A. who have furnished me with a lot of detailed data regarding various aeronautical research activities and equipment in Sweden. I believe that the list of references indicates fairly well the names of the scientists to whom my gratitude is particularly directed. For valuable help on the language side I am indebted to Mr. B. Noton.

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DISCUSSION

MR. A. E. WOODWARD-NUTT (Ministry of Supply, *Fellow*): Everyone who had heard Mr. Lundberg's lecture must be impressed by the amazing variety and extent of the research and development work in aeronautics which was being done in Sweden in spite of the severe limitations in their resources. The lecturer had, of course, only been able to refer to unclassified work, which must be but a fraction of the work they were doing, and probably not the most up-to-date fraction either. Sometimes in Great Britain they found that they were trying to tackle a problem on which work was being done in parallel in the United States. They felt very much the poor relation, and that their resources were pretty inadequate for the job compared with those which the Americans could bring to bear. But they liked to feel that because of this they gave a lot more thought to the way in which they did the job, and that for that reason the results they got were sometimes even better than those obtained on the other side of the Atlantic. He felt that much the same applied, perhaps even to a greater extent, in Sweden. He thought that the illustrations in the paper showed this up well.

In the written paper, Mr. Lundberg had pointed out that the technical staff of the F.F.A., the Aeronautical Research Institute in Sweden, numbered 140, of whom only 35 had university degrees; yet the list of reports published by this Institute was pretty impressive, and many of the illustrations given in the Lecture showed the sort of work they did. The paper was full of elegant solutions to most difficult problems.

He was particularly impressed by two matters. One was the scheme for underground magazines for storage of compressed air for engine testing and for wind tunnels and, the ingenious "Dampometer," which had nothing to do with a hydrometer, but which was an apparatus which in a most ingenious way measured the damping of oscillations, and was used, *inter alia*, for obtaining aerodynamic damping derivatives.

Mr. Lundberg, quite deliberately, he believed, had avoided reference to the financial aspects of the development work, but he was a little intrigued to gather that the F.F.A. appeared to function under the aegis of the Ministry of Commerce, yet with money largely supplied by the Ministry of Defence! No doubt there were good reasons for that, and of course even in Great Britain they had a curious institution called the Ministry of Supply, about which ribald comments were sometimes made, but which dealt with both civil and military aircraft problems.

Another example of Swedish enterprise quoted by the lecturer was that of the Thulin firm; they designed and built 99 aeroplanes of 14 different types and about 700 engines of six different types, but he had omitted to say that they did all that in four and a half years. That was in the written paper, and further, the maximum size reached by the firm during that four and a half years was a total of 900 employees. As Mr. Lundberg mentioned, the Managing Director was also the Chief Designer and the Chief Test Pilot. He wondered how many of their Managing Directors could compete with that.

Mr. Lundberg had also referred to the Saab 29 fighter. He believed that this was the first swept-wing fighter in Europe to go into production, and was delivered to the Royal Swedish Air Force in 1951. Further, he was given to understand that the Draken, that little delta aeroplane, in its first 2½ years—no just over 2 years—had done over 500 hours flying. It would be interesting to know how many hours it had done since.

He was told recently by an Englishman who had spent a good deal of time in Sweden that the Swedish believed that they could do most things better than most other people. Judging by Mr. Lundberg he could only agree, and say that was yet another thing the Swedish had in common with the British.

He thought this remarkable paper would act as an inspiration to research workers in aeronautics everywhere.

DR. P. B. WALKER (Royal Aircraft Establishment, *Fellow*): Mr. Lundberg's paper was remarkable for its versatility. He had had the opportunity of reading the paper and it was most interesting. It started off with static testing, and was a little plaintive when Mr. Lundberg said that he suffered from lack of equipment, and attributed it to the smallness of his country. He did not know how large Mr. Lundberg thought his country was, but he could tell him that we also suffered from shortage of structural equipment. But in reading Mr. Lundberg's paper he did see one advantage, and that was that one man had been able to obtain a complete grasp of all the aspects of research that were being done in his own country, Sweden; and so perhaps the limitation of size was not entirely a handicap. He wished that he knew half of what was going on in Great Britain.

He was very interested in the suggestion that in Sweden they were developing a heat resistant plastic and wondered if Mr. Lundberg could be persuaded to say more. He was also interested in the two gauges which read simultaneously the strain at a point in a structure and the temperature. From what he knew of Swedish ingenuity in design of measuring instruments, this was very interesting and he would like to find out more about it. But one suspected that Mr. Lundberg's main interest was structural fatigue, which was the subject of the Wright Brothers' Lecture to which the President had referred. The introduction to that lecture was most interesting because Mr. Lundberg pointed out that fatigue in aviation was a disease of maturity. The Wright Brothers and the early pioneers solved the problem of fatigue by ensuring that the aircraft never lasted long enough. This was an interesting new thought and he thought it quite a stroke of genius on Mr. Lundberg's part to put it that way. As aircraft structures had steadily improved in all other respects, fatigue had inevitably become a greater danger.

He was very interested to hear that in Sweden they were testing a thousand notched specimens to establish scatter and it was actually stated in print that the ratio of the weakest to the mean was one to five. He remembered not very long ago when he was challenged by 22 lawyers because he tried to claim a figure only as high as three to one. He had therefore been very pleased to read this because he quite agreed that five to one was possible in certain circumstances, and he was happy to feel that in saying that three to one was not unusual he had such support from Mr. Lundberg.

There was one point on which he disagreed—the statistical approach to some of these fatigue problems. He was usually in disagreement with statisticians, but here the main disagreement concerned only the proposal to ask for a guaranteed accident rate of not more than one in ten to the ninth flying hours, and to make this an international standard. He thought where fatigue was concerned that sort of assessment did not work. The risk of a fatigue failure increased with time and he could not accept the implications of simple proportionality behind the one in ten to the ninth. He felt that much depended on whether the aircraft were new, or whether they were old, but his main objection was to this kind of approach to fatigue accidents generally. In his view it was really immoral to start saying: "Well we are going to be all right if we only have one accident in X hours." If they started that way he thought X could easily become 10 X. What they should say was that as far as they could see there would be no accidents at all. If there were something wrong with the aircraft, and he meant passenger-carrying aircraft, and the fault was known, it ought to be put right. The unforeseen things could provide quite enough material for the accident statistician.

There were several quite profound thoughts in the paper with which he not only agreed but sincerely admired, and he had never seen it put quite so clearly that any factors of safety they were going to have for fatigue were entirely different from anything that had been done before, in so far as they must depend on the material used and on the type of structure to which they were applied.

R. J. B. WOODHAMS (Chief Designer, Air Service Training Ltd., *Associate Fellow*): On the question of fatigue he thought that Mr. Lundberg had really come out into the open and given a workable figure of 40 years, even though Dr. Walker had tried to hush him! They now had something concrete to work on at least.

A point on which he could not agree less was the question of different reserve factors for determinate and redundant structures. Surely a redundant structure could be expected to have a lower reserve figure rather than a higher, for the reason that a fatigue failure was not merely dependent upon stress but rather with rate of change of stress per unit length which must, in any case, be higher on a determinate structure than on a redundant.

N. E. ROWE (Blackburn and General Aircraft Ltd., *Fellow*): Like two previous speakers he had had the advantage of seeing the paper, but for him it was no more time than to glance through to be amazed by its tremendous coverage in the aeronautical field and to be tremendously impressed by the ingenuity shown and the scope of all the work.

Mr. Lundberg had showed work on Perspex on the structural side and that was something which they had been doing a little of themselves, at Blackburns, not with very great success he thought because it was obviously a highly specialised technique and required a particular approach. Would Mr. Lundberg tell them if he had found it useful in design, if it were a method which could be relied on to guide designers, and whether it showed any correlation with the theoretical approach? It was extremely valuable because it was so simple. If one could master the technique he thought it was a method which could be used like small models in the wind tunnel—changes could be made quickly and comparative results could be derived of a qualitative kind; if it also gave a good correlation with theory, it might be extremely valuable.

On the question of the general approach to fatigue he was deeply impressed by the fruitful results of the statistical approach. At the same time, on a practical point, he never knew whether the statistician could tell

when this failure was going to occur in the total sequence. For instance, in the 40 years referred to, was this failure going to occur in the first year or in the tenth year or in the fortieth year and if it occured in the first year could they then say that they were going to be all right for the next 39 years? That would be a very good thing, but he wondered how it all worked out. It had always been a puzzle to him how time element was taken into account in such a statistical method; he would be very glad to hear what Mr. Lundberg had to say on that matter. Mr. Lundberg told them also that in approaching the fatigue problem he had made tests with stepped loads and with the normal cumulative damage theory and he had warned them of the difference in the results in two respects, the probability and slope, and had told them to beware how they took those. At the same time the difference was very big and he would like to ask Mr. Lundberg how far the stepped diagram he showed reflected the data he himself had been collecting on the frequency of strains on various kinds of aircraft? He thought there was some evidence that the stepped application did make quite a difference and anything that could really bring actuality into this difficult field, where they were still in doubt as to how various loads really affected fatigue, would be of great advantage.

Looking at some of the performance work, he wondered if some fundamental performance parameter, such as the take-off, were used as a basis for the comparison between jet engines and reciprocating engines because it was rather surprising, he thought, that the jet engine showed such an advantage at such low speed on the comparison of payload and maximum load.

In his paper, Mr. Lundberg said that because they had to be right in the building of aeroplanes they put a great effort into their research and it naturally tended to have emphasis on the practical side, which he had called applied research. Everyone tried to do the same thing. All their work he thought was an attempt to build aeroplanes that would be right but it rarely worked out that way. He would very much like to know from Mr. Lundberg whether he had really been successful in this, which was an absolutely major point. If by applying the ingenuity he had shown, the sort of approach he had shown, they could eliminate the troubles they invariably found when they started to fly the aeroplanes, and actually put them into the air, that would be a tremendous advance.

D. M. JAMESON (Air Registration Board, *Associate Fellow*): He remembered Mr. Lundberg coming to I.C.A.O. in 1946 and arguing for an international requirement on fatigue; he thought that showed considerable prescience and he had not realised that there was, even then, so much knowledge behind it. He thought they were a lot nearer a requirement now, although they still had some way to go.

The points which he would like to take up, in a purely private capacity and as someone who did not know very much about fatigue but who had dabbled in statistics from a performance point of view, were the questions of philosophy and the accident rate. It seemed to him that one must support the statistical method, otherwise, if one took for example Dr. Walker's thesis that it must not happen, the logical conclusion was that the Certificate of Airworthiness could only be given to an aeroplane when the last of its type had completed its useful life without an accident. That would be rather impractical.

What they were really interested in, and this seemed to him to be the nub of the problem—and this might answer Mr. Rowe's worries—was not predicting when an accident would occur, but ensuring that when a passenger stepped into an aeroplane there should be a certain probability of his stepping out of it again in one piece! One could not tell on which flight the accident was going to happen; if one could, one obviously would not get into the aeroplane! The concept of a rate, that was one in so many hours or flights, might be all right for Service use where one signed on for five years or the duration and expected to fly both new and old aeroplanes in that time; but for a civil passenger the probability of an accident on a particular flight appeared to be what mattered and from the airworthiness point of view, one was concerned with the worst flight, that was the one before the aircraft was grounded or a part of it renewed or inspected as the case might be. He thought from the little he had looked at it, one might draw a conclusion (this was from other work, he had not had the benefit of seeing Mr. Lundberg's paper) that on the worst flight the failure probability was liable to be at least ten times as great as the average probability over a lot of flights on old and new aircraft. In other words a probability per flight of 10^{-8} might correspond to an overall rate of 10^{-9}. As regards the choice of figure, 10^{-7}, as a total structural fatigue failure probability on the worst flight, would perhaps be a more practical target to aim at to start with; although because there were a number of parts of an aeroplane which were liable to fail through fatigue, the probabilities for individual parts might need to be lower. The suggested figure took account of the high probability of a fatigue failure being followed by a serious accident, and that such failures were only one cause of accidents.

For comparison, it might be of interest to mention that it was hoped that the performance incident probability of about 10^{-5} used today would give a performance accident probability of 10^{-6} or lower. In this connection one had to bear in mind that many performance accidents were less severe than structural accidents and that in taking care of performance accidents one took care of numerous detail failures to function.

C. M. BRITLAND (Royal Aircraft Establishment, *Graduate*): There had been much talk about fatigue and the structural side but he would like to say a few words on the aerodynamic research which Mr. Lundberg had described. It was particularly interesting to see his photographs of types of flow on swept-back and extreme delta configurations. In the aerodynamics field they were seeing quite a lot of that sort of flow visualisation these days and he thought many people were still trying to make up their minds just how much

such flow patterns really told them. Also, the Draken type of layout with its vortex flows from the leading edge was the sort of problem which would be met quite a lot in the future in supersonic aircraft and the Draken was probably one of the few aircraft now flying in which this sort of flow had been experienced in a stable and manoeuvrable régime of flight. When leading-edge vortex flow was encountered on swept wing tailed aircraft it was likely to introduce instability and one could not investigate it in much detail.

He would like to ask Mr. Lundberg what their flight experience had been on the Draken in Sweden, whether it had lined up well with their tunnel experiments and, in particular, whether there had been any marked Reynolds numbers effects on the vortex flows; also, whether those flows had given rise to any form of buffeting or marked assymmetries, or any sort of unpredictable behaviour of that kind?

He noticed that on the diagram of the large intermittent wind tunnel there appeared to be quite a complicated adjustable diffuser. Would Mr. Lundberg say what their objective was here: he had quoted running times of the order of ten seconds or so, which was normally adequate for force measurements. Had they had much difficulty in pressure plotting work, for example, in that sort of running times, and had they found these complicated second throats a worthwhile device for the purpose of prolonging running times at a given Mach number or for increasing the usable Mach number for the given plant?

SIR SYDNEY CAMM: They had listened to a most interesting survey of research in Sweden—an unusual one, because it had combined structures and aerodynamics. In his opening remarks the lecturer referred to the departure of design from art to science. They had been saying from the very earliest days of aviation that there was going to be less of art and more of science, but there still remained the necessity for extreme ability in combining all the conflicting requirements to which aeroplanes had to be designed.

It might be said that the importance of research would vary according to whether it was to be applied to civil or military aircraft. In this connection he thought that they had been too ambitious in thinking of supersonic flight as applied to civil aircraft. He could not help feeling that this was a long, long way away as far as civil aircraft were concerned.

Mr. Woodward-Nutt referred to the small numbers employed, and that interested him very much as he thought that the employment of large numbers in the design office was perhaps somewhat overdone. He felt that the small numbers employed on research in Sweden was an advantage in some ways.

MR. LUNDBERG'S REPLY

MR. WOODWARD-NUTT: Mr. Woodward-Nutt's remark that it might be a certain advantage for a comparatively small country to be forced to devote a lot of thought to the way in which the work was done, was an interesting one. It might also be stated that planning of research and development work was considerably easier in a small country with a small number of research centres. He wished to emphasise, however, that these advantages were no compensation for the tremendous differences in resources between, for instance, Great Britain and Sweden. One had to bear in mind that the amount of research and development work required for the creation of, for example, a new fighter was of course practically the same in all countries, regardless of their size. This imposed a limit to the size of a country below which design of modern military aircraft would be impossible in practice.

Regarding the hours of flying of the Draken he must refer Mr. Woodward-Nutt to the Saab Company.

DR. WALKER: The F.F.A. would be pleased to furnish Dr. Walker with all available information on their work on strain gauges.

Dr. Walker raised an interesting point by observing that the ratio of the weakest specimen to the mean could be as low as one to five according to some Swedish tests of large sample size, whereas he previously had had difficulty in convincing people that even such a moderate ratio as one to three could often be expected. As this matter of the possible total scatter was of importance for the question of the soundness, or necessity, of a statistical approach a few words might be said about it.

It was evident that the concept of the "weakest" specimen was a very vague one, to say the least, as the weakest specimen that was likely to be found depended on the sample size. The ratio of the "weakest" to the mean might be 1/3 for a sample size of 100, 1/5 for a sample size of 1,000 (as in the Swedish test series) and possibly 1/10 for a sample size of the order of 100,000. It was thus obvious that a factor that should cover the weakest would vary with the sample size. To make the factor dependent on sample size, *i.e.* on the number of specimens or aircraft considered, was nothing but a statistical approach. The statistical nature of the problem could not be circumvented by requiring a more or less arbitrarily chosen factor. Any specified factor corresponded always to a certain probability of failure for any given type of design. Therefore it seemed much more logical and rational to determine first, in one way or another, a reasonable probability of failure and then to calculate the corresponding factor, rather than to guess a factor and be left in the dark as to what probability of failure it corresponded to. In the latter case the factor could easily become either unnecessarily large, implying excess weight, or too small, meaning an unduly high probability of failure.

On the question of what "a reasonable probability of failure" should be and with reference to Dr. Walker's particular comments on the statistical approach to the fatigue problem, he would like to refer to his recent paper, "Fatigue Life of Airplane Structures"[53]. In that paper he had compared rather extensively three methods of defining the safety concept with regard to fatigue, namely the probability of failure itself, the risk of exposure per hour of flight, and the failure rate defined as the probability of fatal failure divided by the corresponding elapsed time of flight. For reasons explained

in the paper he believed that the failure rate was the most appropriate basis for the safety concept. The failure rate obviously took into account the influence of the duration, *i.e.* how old the aircraft was, and it was also consistent with the terms in which accident statistics were presented.

He had emphasised that the important question of the appropriate magnitude of the maximum failure rate should preferably be dealt with by the competent authorities in the various countries and by I.C.A.O. The figure of 10^{-9} was merely a first suggestion indicating what he felt was the right order of magnitude and corresponding approximately to one catastrophic failure in the next 40 years. As pointed out in Ref. 53 this failure rate did not mean that it was absolutely certain that just one fatal failure would occur during the period. Statistically seen, the failure rate only implied that if a considerable multitude of 10^9 hours were flown, the number of failures that could most likely be expected would be 10^{-9} times the total flying time. In 10^9 hours the number of failures might be zero, but it might also be 1, 2 or 3, or even more, although that would be highly unlikely.

It might be added that anyone who felt that the suggested value of the maximum failure rate (10^{-9}) was unduly high should logically plead for a still lower figure, for instance 10^{-10}. This value would correspond to one probable fatal failure in say the next 100 years, assuming a reasonable growth of commercial aviation. In practice that would be very close to a complete elimination of the risk of fatigue failure, but personally he thought that it would also imply an undue penalty in structural weight.

MR. WOODHAMS: He was glad that Mr. Woodhams agreed with his point of view on fatigue both as regards the statistical approach and the fact that the reserve factors should have widely different values for determinate and redundant structures to provide the same level of safety.

MR. ROWE: He thought that the answer to Mr. Rowe's questions about the value of tests with structural models in plastic materials could be summed up as follows. Perspex models were particularly useful in design because they could be made rapidly, cheaply and they could also conform reasonably closely to the actual structural design configuration. Furthermore, to get sufficiently large strains and deflections in the model, only loads of small magnitude need be applied. Provided that the correct experimental techniques were used and great care was taken in analysing the results, then very accurate values could be obtained with plastic materials. There was no reason why good correlation with theory could not be obtained, provided that the correct structural properties were used for the plastic in the theory and, that the theory was correct. The application of Perspex models was limited to pre-buckling loads.

With respect to the statistical approach to fatigue and in particular to Mr. Rowe's question as to when a fatigue failure was going to occur, he would like to draw a parallel case with the probability of a person being struck by lightning. There was a certain risk for such an occurrence during each period of thundery weather, but it was impossible to state when it would happen, which was one of the characteristics for all matters of probability. It might also, unfortunately, be remembered that if a person were lucky enough to survive being struck by lightning, then it did not make him immune from being struck again.

With reference to Mr. Rowe's questions about fatigue tests with step loads (he would prefer to call it loading with varying amplitudes or programme loading, as the loads also could be varied continuously), he wished to point out that the particular load programme used in the tests corresponding to Fig. 59 did not represent a typical load spectrum for aircraft for reasons stated in the paper. He quite agreed with Mr. Rowe that the correlation between programme testing and *S-N* testing constituted a big research field and he must emphasise once more that both these methods of testing were necessary to increase knowledge about fatigue.

The main basis for the comparison of the performance of jet engines and reciprocating engines was the assumption of the same wing loading (*i.e.* the same landing speed with equal lift coefficient) for the two cases as stated in the caption to Fig. 25. He might add that the comparison was made with the qualities of jet engines feasible in 1944. The improvements made since then should give ample allowance for the fact that the jet aeroplane had to carry an extra reserve of fuel due to the high fuel consumption.

MR. JAMESON: He was very pleased to find that Mr. Jameson agreed with the statistical approach to the fatigue problem, particularly as he knew that Mr. Jameson had made several contributions with regard to the statistical treatment of performance. Mr. Jameson's comparison with the probability of failure, or failure rate, due to performance accidents was very interesting indeed. It was his general feeling that, to deal with performance problems in a statistical way was a more complicated matter than was the statistical treatment of fatigue problems. As a statistical approach to the performance problem was being seriously discussed and partly adopted, this spoke in favour of using statistical methods for the fatigue problem also.

MR. BRITLAND: With respect to Mr. Britland's question about the Saab Draken, he would prefer to refer him to the Saab Company.

The objective of the adjustable diffuser was to improve on the required pressure ratio. In practice this meant that with the adjustable diffuser they could work with a higher pressure in the rock chamber, requiring shorter pumping times, for attaining certain running times, or, alternatively, they could attain longer running times with a certain pressure in the vacuum chamber. A considerable increase in the maximum Mach number could also be obtained.

For pressure plotting, running times of 10 seconds were normally adequate. However, in some cases it was necessary to make a second run before the manometer readings were taken, in particular when very fine pressure tubes had to be used.

The Application of Air Survey to the Economic Development of a Country

by

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THE PURPOSE of this paper is to attempt a broad review of some of the factors that influence the economic development of a country and to illustrate in general terms the importance and the application of air-borne survey techniques, as a means of collecting the information on which any sound development must be based.

The industrial and agricultural revolution that is now taking place on a world-wide scale demands a completely new approach to the problem of economic development. When economic development was slow and confined to small areas it was sufficient perhaps to base that development on limited information. Today, however, the pace is quickening every year, but the speed with which we are obtaining the information, on which such development must be based, is lagging behind.

Why is the present position different from any other epoch in world history? The main cause is the industrial revolution, which has produced rapid means of communication, by air and by radio. The Twentieth Century now lives literally as neighbour to the Stone Age. This has produced a dissemination of ideas on a world scale and has made comparisons possible between peoples that previously had no contact. A second factor is the political one—the growing strength of nationalism. Countries which were growing gradually to self-government now want to throw off the yoke of tutelage and run their own affairs unaided. They wish to become economically self-supporting. Countries whose economy was often based on one major industry or crop wish to broaden the balance of their livelihood.

The third factor is the economic one: the now universal demand for an increased standard of living. The demand for an improved standard of living means an increased demand on the raw materials for manufacture. More bicycles, pots and pans and refrigerators, will mean an unprecedented increase in the search for raw materials and synthetic substitutes.

The fourth factor is the moral one. The conscience of the West has been stirred by the comparison between the highly industrialised and wealthy nations and the low standards of the under-developed countries.

The fifth factor is the political one: the division of the world into two opposed political and economic systems, both fighting to win the allegiance and support of the less developed countries.

The sixth factor is the rapidly increasing world population. The population of India in 1951 was 360 millions. In 1981 it is estimated to be 520 millions. It is also estimated that food production in India can be increased to feed a maximum of 450 millions by that date. Will India be able to industrialise sufficiently to find other ways of feeding the balance of 70 million? It is estimated that the population of the U.S.A. in 1975 will be 210 millions as compared with 154 millions in 1950.

The aggregate consumption of raw materials in America is likely to grow by 55 per cent. in the period 1950-1975. This will make the American economic system more and more dependent on the import of raw materials from under-developed countries.

In the United States over 10 cwt. of steel are used per head of the population each year; in India little over 10 lb. It would be unrealistic to suppose that the rates of consumption in under-developed areas will quickly reach those of the U.S.A., but the growth of their own industries will put heavy pressure on resources.

"The first asset of any country is, of course, its people, whose increase is an opportunity as well as a threat. There is an old saying that 'with every mouth, the Lord sends a pair of hands.' Additional hands are useless without land and raw materials to work on; without tools, equipment and power to work with; and without trained technical guidance and organisation to direct their work."

The above is an extract from the report on the Economic Development of Ceylon, prepared by the Mission organised by the International Bank for Reconstruction and Development.

We are faced, then, with a rapidly changing world, a world that has suddenly shrunk; where the demand for an increased standard of living is growing steadily and where political power is being more and more widely spread.

Many organisations, both national and international, are attempting in their various ways to deal with this problem. The United Nations, through its Technical Assistance Programme, the World Health Organisation, the International Bank, the Food and Agriculture Organisation; the U.S.A. through its Foreign Operations Administration (successor to the Point IV Programme); the U.K. through the Commonwealth Development and Welfare Fund, and in combination with Commonwealth and other countries through the Colombo Plan, are all making their contributions.

It is easy to criticise the "aid" organisations, and many stones have been thrown, and perhaps some

*A Section Lecture given on 31st March 1955.

deserved, but nobody can deny the tremendous benefits that have already accrued from the work of these organisations. It is often forgotten how complicated is the problem of economic development, particularly of an under-developed country with a very low standard of living.

The ground nuts experiment is perhaps the outstanding example of how not to carry out a development project. It may yet, however, be counted worth while if it has taught sufficient people the necessity of studying all the relevant facts about an area before bringing in the bulldozers.

Mankind's present problem has been ably stated by Fairfield Osborn:

"The tide of earth's population is rising, the reservoir of earth's living resources is falling. Technologists may outdo themselves in the location of artificial substitutes for natural subsistence, and new areas such as those in tropical or sub-tropical regions may be adapted to human use, but even such resources or developments cannot be expected to offset the present terrific attack upon the natural life-giving elements of the earth. There is only one solution: Man must recognise the necessity of co-operation with nature. He must temper his demands and use and conserve the natural living resources of this earth in a manner that alone can provide for the continuation of his civilisation."

Quite a large body of opinion, much of it very vocal, has held the view that the solution to the economic development of an area lay mainly in supplying sufficient money to start industries and public works schemes and the like. This has recently been the subject of a study initiated by the Secretary-General of the United Nations. In their report headed "Processes and Problems of Industrialisation in Underdeveloped Countries" they state: "In the last resort each country has to devise and organise its own development process, adapting its industrialisation effort to the basic economic realities of resource endowment, population growth, production pattern and social structure." One of their main conclusions is as follows: "Industrialisation must be considered as being merely one part of the total process of economic development. Development plans for industry cannot be framed in isolation; they must be integrated with plans for development of agriculture, mining, transport, power and all other sectors of the economy. This is true even within an economy which is well endowed with natural resources."

If this is true, then surely no sound economic development programme can be framed until accurate and comprehensive information is available on the basic resources of the country involved. Professor Nurkse in his recent book "The Economic Impact on Under-developed Countries" has also stressed the difficulties of under-developed countries in absorbing capital, and to what a great extent success depends on the attitude of the people, the integrity of their administration and their ability to save.

Another difficulty is the political pressure which demands that development work should proceed, and forces it through despite the lack of adequate information, and often against the advice of the technical staff.

The International Bank has recently announced the establishment of an Institute for Development, where senior officers of the member governments will attend to study the problems of development. This has been done because it is considered that full advantage has not been taken of the Bank's loans due to the lack of trained personnel in the countries concerned. Equally, if not more important, is the need for the Bank to base its reports and recommendations on comprehensive and accurate information. At present the Bank can only act in an advisory capacity, and its technical missions must base their recommendations on their own investigations and whatever information is available in the country, but as the need for this information becomes more appreciated perhaps ways will be found whereby the Bank, either directly or through an associated organisation, will assist in financing a resources inventory programme.

The economic development of many areas depends on attracting investment capital. The political hazards in many countries are serious enough, but if in addition to those the investor is presented with virtually a blank map, the prospects cannot be called inviting. The oil companies are large enough to risk the exploration expenses, but few other organisations can afford to do so. They must therefore rely on the governments carrying out the basic survey. But most probably the Government Survey Department cannot provide the information required. Alternatively they must seek assistance from an organisation such as the International Finance Corporation which is being set up in close association with the International Bank, in order to assist private investment in under-developed countries.

A great deal of technical advice and assistance has been given from one country to another, and through U.S.A. and U.N. agencies since the war, and much valuable work has been done. However, the criticism is often made that too much advice has sometimes been given, and often based on too little information. Too frequently the reports have been pigeon-holed, and nothing done to implement the recommendations made. Much of this criticism arises from an incorrect use of the expert. If the visit is only a short one, as most are, he can only give his opinion on information already collected and very often this is neither adequate nor reliable.

Probably the most valuable and objective advice given to countries since the war on economic development has been contained in the reports prepared by technical missions organised by the International Bank for Reconstruction and Development. The Bank's reports continually stress the need for survey, research and careful investigation before commencing large projects. For example, in its report on Ceylon, in the section on Dry Zone Agriculture, the report reads: "The Mission is convinced that much fuller knowledge is needed to avoid tragic mistakes and that a firm requirement is much more survey work on topography, soils and land use potential. These should be Island wide, with more detailed treatment of selected areas. Of prime urgency is aerial topographic mapping on which soil, land use and water surveys can be based."

We have, therefore, a situation where economic development is being hastened for a number of reasons, political, economic and social, and where statisticians are busy with claim and counter claim on the vital point of whether population and industrial output will outrun the available resources. These statistics should not be taken too seriously because our ignorance of the extent of the existing and potential resources is still far too great. Too few people appreciate the extent of our ignorance.

Topographical Maps

An analysis of the world position in regard to topographical maps was conducted by the U.N. in 1949. The following general statement is probably reasonably accurate:—

"(*a*) Less than 2 per cent. of the land areas of the world are mapped on scale of 1/25,000 or larger, essential as such maps are for planning, development and administration.

"(*b*) It is doubtful if more than 25 per cent. of the land areas of the world have even reconnaissance maps of 1/300,000 or 1/250,000 scale or larger, compiled from aerial photographs or systematic ground surveys.

"(*c*) With the possible exception of a few European nations and very limited areas in other countries, the status of surveying and mapping is nowhere adequate for full and economical development of natural resources.

"(*d*) ... it is significant that the nations in which the status of surveying and mapping has been highest for many years, are now expending much larger sums in proportion to their national wealth and population to improve their maps, than are the less well mapped nations. This indicates the appreciation of higher quality maps where they are available."

The first requirement for any development planning is a topographical map. This is the responsibility of the Government Survey Departments. But in many countries these are comparatively young organisations, and usually their limited staffs have to concentrate on the urgent requirements of property, cadastral and special project surveys. It should also be remembered that until the advent of the aeroplane it was virtually beyond the means of survey departments to tackle the enormous problem of preparing accurate topographical maps of vast areas.

It was only at the end of the 1939-45 War that the task of mapping the British Colonial Empire was tackled and the work centralised under the Directorate of Colonial Surveys and aerial survey accepted as the method. It has recently been stated in the report on the Colonial Development and Welfare Fund, that of the 800,000 sq. miles that was set up in 1946 as a 10-year target for the Directorate of Colonial Surveys, they have only been able to complete 300,000 sq. miles due to other high priority project surveys. The figures give an indication of the state of basic mapping in the world, when of a total of 2 million sq. miles in the British Colonial Empire, only 300,000 sq. miles have been mapped, and most of that in the form of a preliminary plot at 1/50,000 without contours.

The Directorate of Colonial Surveys suffers the fate of most Government Survey Departments in having its basic programme interrupted by high priority project surveys, one Government Department considering that a saving is being effected if the work is done by another Government Department. As nobody can assess the loss in revenue due to the inadequacy or absence of basic maps of the Colonies, no further action is taken.

Geological Surveys

The state of other forms of mapping, geological for example, is far behind that of the topographical mapping programme. In many countries the position is far worse.

The U.N. experts who collected all available data for the Economic Survey of South-East Asia and the Far East (1949) concluded: "The knowledge of mineral reserves in the region is quite inadequate, principally because such knowledge has been a function of the extent to which mineral resources have been used."

A great deal is known about tin deposits in Malaya, but the report states that only 3·5 per cent. of the area of the Federated States had in 1949 been geologically mapped on a practical scale. Of India with a century-old Geological Survey, only 28 per cent. has been mapped on a one-inch scale; of Indonesia only 8 per cent.; of Thailand none at all.

An interesting paper was recently read on Mineral Resources Strategy by D. A. Oliver to a Conference organised by the Department of Scientific and Industrial Research, on Research and Industrial Productivity. The theme of this paper was "that minerals productivity will be increased if greater co-ordination of the right kind can be established between all the interested parties." Mr. Oliver pointed out the need for long-term planning, both as to the users' requirements and from the exploration point of view. He pointed out that the geological survey work done by Government Departments stops at a relatively early stage and that on the whole British mining interests, due to a variety of reasons, have shown great caution in continuing the investigations. He recommends the setting up of an Independent Committee of Enquiry involving particularly the Ministry of Supply, the Board of Trade, the Advisory Council for Scientific Policy, the Commonwealth Relations Office, the Colonial Office, and D.S.I.R. to study the factors and needs attached to the mineral industry.

A study should be made as to whether or not the present speed of geological exploration in the Commonwealth is sufficient to meet the estimated needs of the industry during the next decade. Secondly, whether greater use could not be made of new techniques and, in particular, airborne methods which can help to reduce the time-consuming work of ground survey.

There is surely a need for similar enquiries dealing with the other basic natural resources, the land, soils, water, forests, and for a Commonwealth exploration programme to be drawn up with the aim of completing

a resources inventory, even of a reconnaissance nature, in as short a time as possible. Not until such an overall appraisal has been completed can we be sure that the great sums involved in economic development will be spent to the best advantage.

Aerial Survey

Aerial survey used in its widest sense as the application of every airborne exploration method has a most important part to play in this task. The first requirement in an unmapped area is obviously to obtain some knowledge of the topography. Vertical photography is done with a specially modified and equipped aircraft, the flying height of the aircraft and the scale of the photographs being determined by their subsequent use. In some areas it may not be necessary to go to the additional expense of preparing an accurately scaled topographical map. A photographic mosaic made up from the vertical photographs can provide a satisfactory base for recording resources inventory information. The helicopter and airborne electronic aids are both being used to hasten the essential ground survey work involved in any mapping.

Information on land use and its potential must be a high priority in any resources survey. According to Woytinsky, only 7 per cent. of the land area of the world is fully suited to agricultural production. This means that tillers of the soil must either compromise with existing conditions or try to change them. The tendency in the future, due to the increasing population, will be for man to change the existing conditions. Recent experiments in increasing food production in tropical countries have illustrated the need to study and understand the complex relationships that make for a particular kind of land utilisation.

Land is an expendable asset and we cannot afford to misuse that under cultivation, nor to risk bringing new land under cultivation without first assembling and studying all the available facts.

It is in the assembly of such essential facts that the aerial photograph is so valuable. It provides a complete picture of the ground, which can be studied in three dimensions, with all the detail of vegetation pattern and drainage. With the air photograph the scientist is able to study the area before starting field work, to look at it as a whole, and to plan in detail the field work and ensure that sample areas chosen for investigation are representative.

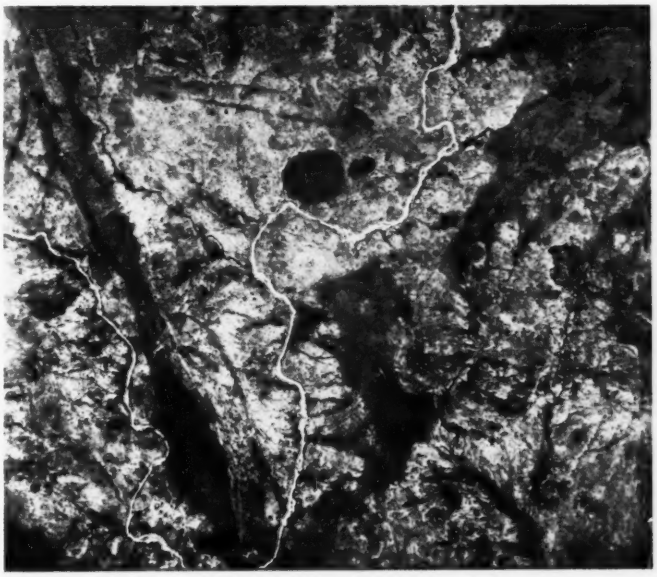
Land use planning should operate in three main phases, in each of which the use of aerial photographs is of major importance. First, essentially a reconnaissance phase, is the mapping of present land use. Much of the work can be done by photo-interpretation with restricted ground sampling. This phase should serve as a basis for the selection of areas which seem likely to warrant further investigation.

The second phase would be the recognition and mapping of geology, soil units and vegetation units. At this stage, an assessment is made of the existing natural resources. This involves more field work, but the principles concerning the use of air photographs remain the same, although different kinds of photography may be required to elucidate different problems.

The third phase involves an assessment of how the land could be used or developed. This involves an investigation of the inter-relation of the factors making up the phases to point the way to safe and profitable lines of development.

If the aerial photograph is to be fully valuable in survey work of this kind, not only must its potential use be fully understood but the manner of its taking must be carefully planned so that it will yield the information required. Too often soil surveys and land classification work has to be done from existing photography which was probably taken for another purpose and is not really suitable. Economics must often demand a compromise on this, but too little attention has been given to find the best answer both for the topographical mapper as well as for the soil surveyor.

Perhaps one of the most urgent needs for a study of land use is the scourge of erosion. Everybody has heard of the American dust bowl. These conditions resulted from a combination of factors; ruthless clearing of forests; the frequent use of land susceptible to both gully and sheet erosion for crops requiring a clean cultivation; the vast expansion of wheat fields in the



Vertical photograph of an alluvial tin-bearing area in Nigeria. The varying tone and texture of the photograph show up the geological structure.

Great Plains, with the resulting destruction of the grass cover.

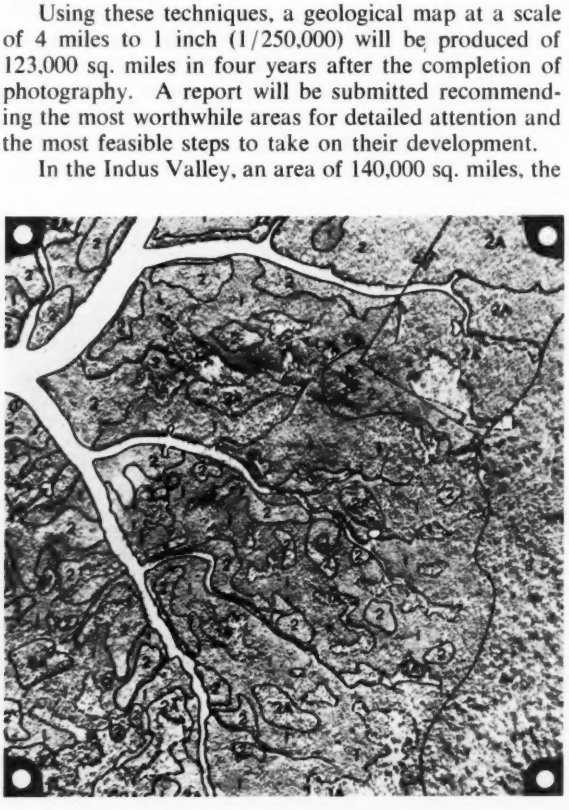
In Australia erosion is spreading rapidly and many millions of acres have been denuded of top soil. In New Zealand more than two-fifths of the total area and more than two-thirds of the occupied area are subject to rapid erosion. In the Middle East soil erosion is visible everywhere. In Ceylon much of the best tea planting country is going downhill.

A good example of a resources survey now in progress is in Western Pakistan. To assist the economic development of Pakistan, the Canadian Government agreed to carry out a resources survey of Western Pakistan as part of Canada's contribution under the Colombo Plan. The work was divided into two parts, a preliminary geological survey of Baluchistan, and a soils and land use survey of the Indus Valley. The whole area, 300,000 sq. miles, was photographed at 1/40,000 scale and mosaics at 1/40,000 made of the whole area.

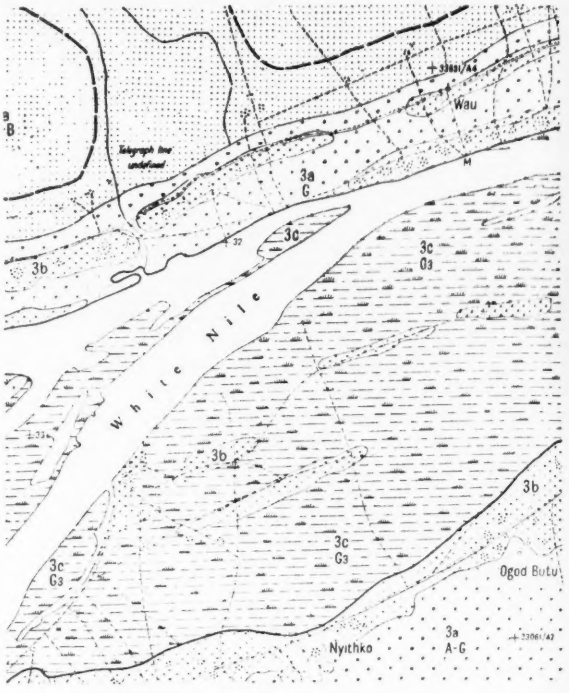
The first step in the geological survey was the study of all available data, its classification and plotting into the mosaics. The second step was the geological interpretation of the photographs. Greatest attention was paid to major geological structures as most economic deposits are related directly or indirectly to structure. The geological parties then carried out their examination, recording their data in field notes and on the mosaics.

Using these techniques, a geological map at a scale of 4 miles to 1 inch (1/250,000) will be produced of 123,000 sq. miles in four years after the completion of photography. A report will be submitted recommending the most worthwhile areas for detailed attention and the most feasible steps to take on their development.

In the Indus Valley, an area of 140,000 sq. miles, the



Vertical photograph of mangrove swamps in Malaya. The annotations 1 and 2 show different species of mangroves, and the suffix "A" denotes older trees of each species.



Soil map in Sudan. Prepared by photographic interpretation and field checking.

purpose of the survey is to provide reconnaissance data concerning the general soil types, present land use and general salinity. This information will be presented in the form of maps at a scale of 1/250,000, with separate maps for agricultural soil types and present land use.

After the preliminary phase of studying existing data and the photographs, selective field sampling is carried out in accordance with soil and land use patterns as they appear on the photographs. By locating samples in areas of essentially uniform photo pattern, the sample results may be extended to cover the entire uniform pattern. The field sampling is being carried out with the aid of helicopters and jeep transport.

Another example of a land use or land classification survey is in Jordan where the work is being done as part of the U.S. aid programme. Jordan is largely a desert country with a high proportion of its population nomadic tribesmen whose living depends on the very variable rainfall. One of the programmes is to improve the grazing facilities for the nomadic tribes. Pilot projects have been carried out to test the effectiveness of various methods, but before the work can be extended it is essential to map the country, dividing it into broad land units. It will then be possible to concentrate on those areas which from the topography, climate, drainage, soils and vegetation aspects look most promising.

An example of a more detailed survey of soils and land use is one being done in Iraq. An investigation is being made of part of the plains area with a view to irrigating and bringing these now desert areas under cultivation, using water stored in the reservoirs now being constructed in Kurdistan. Some people have

Section of geological laboratory.

thought that the plains areas of Iraq, composed as they are of alluvium and having previously been cultivated in Babylonian times, could with the introduction of water, be easily made into rich agricultural areas again. There may be quite extensive areas that can be brought back into cultivation, but others that will not be suitable. Before any recommendation and plan can be made a detailed survey has to be made. Photography flown specially at 1/20,000 scale is being used for the soils and land use mapping.

Extensive land studies are being made by the Land Research and Regional Survey Section of the Commonwealth Scientific and Industrial Research Organisation in Northern Australia. This organisation was established "to initiate a series of land surveys of under-developed regions in order that their developmental potential might be most accurately assessed."

The primary classification of lands has been on a geomorphological basis. A team of specialists was brought together to work in close co-operation in the field and in the laboratory. This comprised a climatologist, geologist, geomorphologist, pedologist, botanist and ecologist. The surveys were based on interpretation of air photographs, as was the field work and the field work followed up by further interpretation and extrapolation of the data obtained to areas of the same photo pattern.

Having classified the various land systems according to their natural characters, land use potential is assessed and recommendations made concerning future development. Between 1946-1950, 236,000 sq. miles were mapped using these methods.

The increasing population means in many countries an increasing fragmentation of the land. By far the greater proportion of people earn their living from the land. Land holding and land tenure is consequently a most important factor and particularly in the under-developed countries. Not until land holdings are registered and recorded whether on a map or by recorded measurements, can there be real security of tenure nor can the Government collect the true revenue that it should be drawing from the land. A proper system of cadastral survey and registration of rights is the essential basis of a real understanding of the agrarian position in any country, and thus to the planning of any measure of agrarian reform.

Until very recently, cadastral surveys have been undertaken almost entirely on the ground by conventional methods. In many countries the laws only allow this work to be done by ground methods, and to accuracies which take no account of the practical realities of the problem. The laws will have to be changed if the problem is to be tackled in a realistic manner.

In Jamaica there are 60,000 properties which require registration but nothing can be done about it because as yet no suitable map exists. Ceylon, which possesses a highly efficient Survey Department, is still without a large scale plan of Colombo, the capital. In Uganda, there is the "milo" problem, in Kenya the Kikuyu Reserve is virtually unmapped.

Recent work has shown that aerial survey techniques, combined with ground survey, and carefully planned according to the circumstances of the job, can assist very greatly in speeding up this important work. Using first order stereo plotting instruments it is possible to meet the requirements within a plottable accuracy up to 1/500 in plan scale. Photogrammetric mapping reduces the ground work to a minimum, is usually between four and six times more rapid and at a conservative estimate the saving in cost of air over ground methods for plans at 1/2,500 scale is in the region of 25 per cent.

Air Survey mapping is now recognised as the quickest and most efficient way of undertaking most engineering surveys required for development work.

With regard to the world's forest resources, the F.A.O. has written that the total potential yield of the world's forests is from three to four times the current world demand. There is, however, the paradoxical state that although in comparison with the potential return, they have only been scratched, in many parts of the world the advance of settlements has been marked by progressive annihilation of forests. Many nations are now facing the difficult and time-consuming

Surveyors examining sample borings in Iraq.

and expensive task of reafforestation. It has been stated that the world's future supply of forest products depends on progress in sylviculture and in rational management of forests. Before any management plan can be drawn up an inventory must be made of the forest resources. Aerial photography interpreted by trained foresters and followed by selective ground sampling is now accepted as the quickest and most accurate technique for carrying out this work.

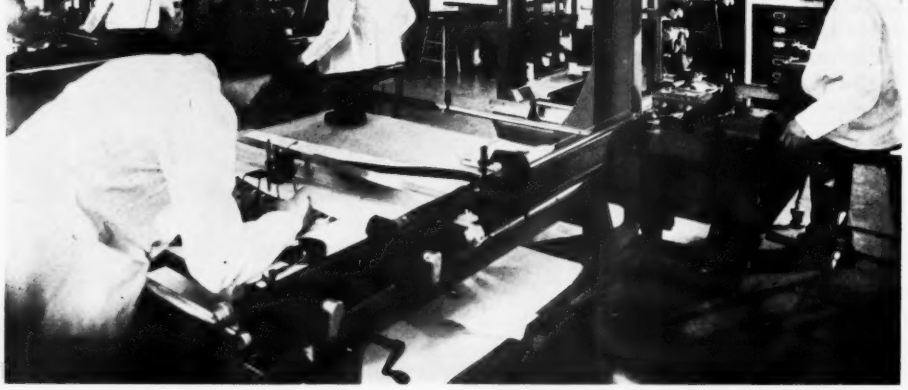
Unlike agricultural and forest resources, minerals in the earth's crust are not renewable. A race has developed between depletion of the known and easily accessible deposits and the search for new fields and new methods of exploration.

The increasing search for oil is one where airborne methods of survey are playing an important part. Aerial photography is now considered an essential preliminary to any exploration programme. Stereoscopic photogeological interpretation of the photographs can reveal not only the topography but also much of both regional and detailed geological structure. Dip and scarp slopes are often visible where hard bands of rock have resisted erosion, and the trend lines of strike and direction and amount of inclination of the dip can be recorded. Localities of geological interest can be rapidly selected for examination and sampling by field parties. Even if no surface geology is visible the preparation of an accurate topographical map from the photographs can save a great deal of time on the ground.

Airborne magnetometer surveys are being used to an increasing extent in the reconnaissance stage of exploration.

Many geological structures favourable to oil are underlain by basement uplifts and thus the detection of the depth and form of the basement surface is one of the principal applications of the magnetic method of oil prospecting. The igneous and metamorphic rocks that compose the basement are usually more magnetic than

Part of an aero-magnetic survey conducted for the search for oil. The sheet illustrates the types of anomaly obtained. A distinction can be drawn between the lower half of the sheet where the sediments are shallow and the anomalies are small and numerous, and the upper half of the sheet where the sediments are deep and the anomalies are large.



Wild A.5 stereoplotting instruments. Used for plotting maps up to a scale of 1/480 with contours at vertical interval from one ft.

the over-laying sedimentary types, and where they approach nearer to the surface an increase in magnetic intensity results.

One of the main values of the aeromagnetic method is to isolate areas of interest in which detailed investigations can be made by other means. Recent work over dense jungle country has shown amazing correlations between the results obtained from the more detailed work of the gravity and seismic parties.

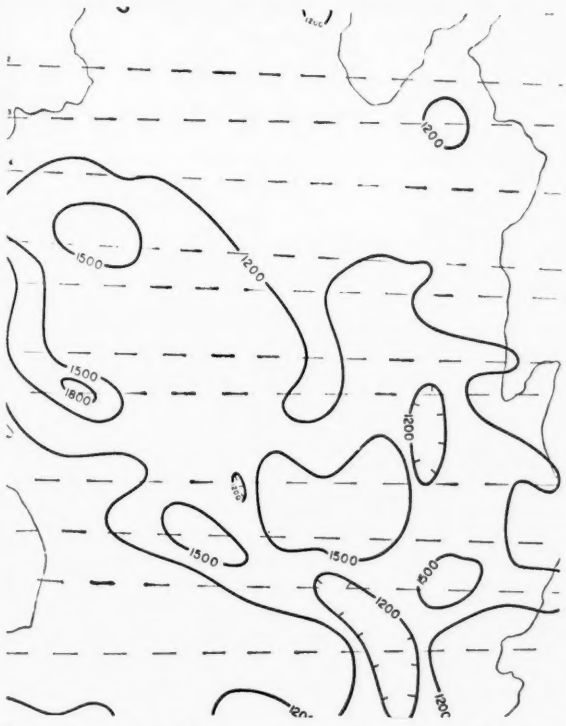
A new development in aerial surveying has been the installation in one aircraft of three separate electronic systems of surveying. Up till recently technical difficulties prohibited the installation of all three in a single aircraft.

The three devices are: The airborne magnetometer which records variations in the earth's magnetic field and aids geologists in the search for iron, oil, asbestos, titanium and nickel.

The scintillation counter, an airborne instrument that gives clues to the presence of uranium in the earth.

The electro-magnetic detector which can directly locate sulphide bodies that may contain copper, lead, zinc or nickel.

The electro-magnetic detector requires a transmitting coil energised with an alternating electric current to surround it with an electro-magnetic field. This field induces electric currents in any conductor within reasonable range (*e.g.* a sulphide body, water, moist overburden), thereby surrounding the conductor with a secondary electro-magnetic field differing from the first in amplitude and phase. Such differences in amplitude and phase are utilised by electro-magnetic systems to detect the presence of the secondary field; at the same time the electro-magnetic detector also measures conductivity, thereby differentiating between poor conductors such as water and better conductors, such as sulphide bodies.



Part of a radio-activity map, prepared as the result of a scintillation counter survey.

Canso aircraft towing an electro-magnetic detector head. This instrument locates sulphide ores.

Under favourable terrain condition—over ordinary wet outcrop for instance, rather than thick wet clay—the primary field will penetrate to depths of 300 ft. below the earth's surface and detect sulphide bodies.

Electro-magnetic and magnetometer findings complement each other neatly; the magnetometer giving a regional picture of geology and structure and also revealing presence of magnetic mineral concentrations: while the electro-magnetic detector indicates concentrations of sulphide bodies which may or may not be susceptible to detection by the magnetometer.

Conclusion

To summarise: for a number of reasons economic development on a world-wide scale is proceeding at an unprecedented pace. Development should be a balanced one taking into account all aspects of a country's economy and resources, and based on comprehensive information. At present the information available and the Government agencies whose main responsibility it is to provide it are inadequate to meet the need. Only by making full use of airborne survey techniques and all the skill and technicians available can the problem be tackled realistically.

The Local Instability of a Simple Integral Panel

by

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SUMMARY: The local instability of a simple type of integral panel under uniform end compression is discussed firstly as a problem of interconnected flat plates, and secondly in terms of the torsional stability of the stiffeners. It is found that the second method under-estimates the "true" local buckling stress. This conclusion is in conflict with earlier work by Yusuff[1]; on closer study it is found that Yusuff's analysis involves two important assumptions which are generally unjustifiable. It is suggested that the collapse strength of a short compressed panel may be estimated with reasonable accuracy from a knowledge of the initial local buckling stress and the proof stress of the material of the panel.

1. Introduction

The structural advantages of integral panels in aircraft construction have been discussed by many authors in recent years. Panels of this type under end compression may fail in a variety of ways; in particular, short panels may be prone to local instability, which leads ultimately to failure of a localised region of the compressed panel. The purpose of this paper is to present alternative theoretical approaches to the problem of the local instability of a simple type of panel with unflanged stiffeners. In practical problems post-buckling behaviour may be important; this aspect is discussed briefly.

Notation

Subscripts 1 and 2 refer to a stiffener and the sheet, respectively.

$A_{1,2}$	constant
$b_{1,2}$	breadth of a component flat plate
$D_{1,2}$	flexural stiffness of a component plate
E	elastic modulus
E_t	'tangent' modulus
G	shear modulus
GJ	torsional stiffness of a stiffener
L	length of the panel
m	number of longitudinal half-waves in the buckled form
Ox, y, z	rectangular co-ordinate axes
$t_{1,2}$	thickness of a component plate
$U_{1,2}$	strain energy of the buckled form of the panel
$W_{1,2}$	work done by the external forces during buckling
$w_{1,2}$	deflection of a component plate in the buckled mode
θ, θ_0	angle of twist of a stiffener
ν	Poisson's ratio
σ	uniform end compression stress
σ_{cr}	critical buckling stress
σ_{max}	maximum average stress of a buckled panel
σ_y	0·2 per cent. proof stress of the material of the panel

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2. Description of the Problem

A short compression panel, Fig. 1, consists of a flat sheet to which longitudinal stiffeners are rigidly attached. The stiffeners are themselves flat plates, so that the panel may be regarded as a set of interconnected plates. The panel is of considerable total breadth; buckling at a remote edge is assumed to have no significant effect at the centre of the panel.

The whole cross-section of the panel is subjected to a uniform compression stress σ. Since the panel is short the relevant mode of local instability involves plate buckling of the sheet and stiffeners; as in many local instability problems the junctions of the component plates remain straight during buckling. The unstable form of the cross-section of the panel is shown in Fig. 2.

3. An Earlier Treatment of the Problem

In treating the more general problem of overall instability of a compressed panel, Yusuff[1] discusses firstly a mode of buckling in which the junctions of the sheet and stiffeners are displaced laterally; he studies

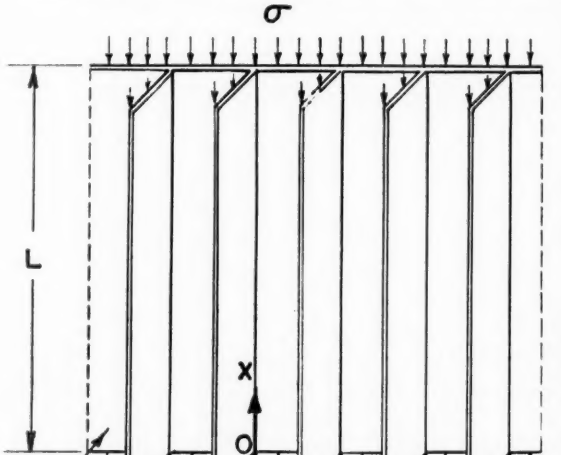

FIGURE 1. Arrangement of compressed panel.

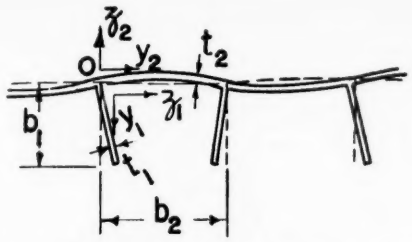

FIGURE 2. Unstable form of the cross-section of the panel.

the problem as one of torsional instability of the stiffeners. From his analysis he concludes that there are two possible modes of buckling; the one is overall strut instability of the usual Euler type; in the other mode the junctions of the sheet and the stiffeners remain quite straight. This latter mode corresponds to "pure" local instability of the panel, although Yusuff refers to it, rather loosely, as torsional instability; for this mode Yusuff gives the elastic buckling stress in the form

$$\frac{\sigma_{cr}}{E} = 0{\cdot}4\left[\left(\frac{t_1}{b_1}\right)^2 + 0{\cdot}357\,\frac{b_2 t_2^3}{b_1^3 t_1}\left\{2+\left(\frac{L}{b_2}\right)^2+\left(\frac{L}{b_2}\right)^2\right\}\right], \quad . \quad . \quad . \quad (1)$$

in which

σ_{cr} is the critical compression stress,
E is the elastic modulus of the material of the panel,
b_1, t_1 are the breadth and thickness, respectively, of a stiffener,
b_2, t_2 are the breadth and thickness, respectively, of an element of the sheet between two stiffeners, and
L is the length of the panel.

For buckling in the plastic range of the material Yusuff suggests the use of the "tangent" modulus E_t in place of E*.

An important feature of Yusuff's analysis is that he assumes the stiffeners and sheet to buckle in a single sinusoidal half-wave in the longitudinal direction; he takes the angle of twist of a stiffener at any section in the form

$$\theta = \theta_0 \sin\frac{\pi z}{L}. \quad . \quad . \quad . \quad . \quad (2)$$

It may be shown, (and this is demonstrated subsequently), that his analysis leads to a materially different result if this restriction is removed.

Yusuff finds that the measured failing stresses in two panel tests are in agreement with equation (1). He suggests that conventional local instability theory, when applied to this problem, under-estimates appreciably the strengths of the panels. He concludes that torsional instability analysis gives a good estimate of the buckling strengths. This conclusion is of considerable interest; it is well-known that some instability problems of flat plates may be discussed in terms of either torsional or local buckling; a simple example is that of a long strip, simply-supported on the compressed ends, simply-supported on one longitudinal edge, and completely free on the other edge; in the torsional instability analysis the flexural stiffness of the strip is neglected, and the critical buckling stress so derived is smaller than that given by local instability analysis[2]. Yusuff's conclusion is surprising because he suggests that torsional analysis gives a critical stress which is considerably greater than the local buckling stress.

Another feature of Yusuff's paper is that photographic illustrations of so-called modes of torsional instability indicate clearly simple forms of local instability.

These considerations lead to two questions of some importance; firstly, is the theoretical local instability stress smaller than the corresponding torsional instability stress? and secondly, is it possible to explain Yusuff's test results on the basis of conventional local instability theory? These questions are examined more closely.

*In the present state of knowledge of the subject it would be difficult to justify this.

4. An Approximate Local Instability Analysis

Suppose all the component plates of the panel, Fig. 1, are simply-supported along the edges $x=0$ and $x=L$; the uniform compression stress σ is applied along these edges. In the mode of simple local instability the junctions of the sheet and the stiffeners remain quite straight. Suppose each component plate buckles in m sinusoidal half-waves in the longitudinal direction. The deflection of a stiffener parallel to $0z_1$ is taken in the form

$$w_1 = A_1\left(\frac{y_1}{b_1}\right)\sin\frac{m\pi x}{L}. \quad . \quad . \quad . \quad (3)$$

where A_1 is an arbitrary constant. The displaced form of an element of the sheet between two stiffeners is taken as

$$w_2 = A_2 \sin\frac{\pi y_2}{b_2}\sin\frac{m\pi x}{L}, \quad . \quad . \quad (4)$$

where A_2 is a constant. For continuity in the yz-plane along the junction of the sheet and the stiffener

$$\left[\frac{\partial w_1}{\partial y_1}\right]_{y_1=0} = \left[\frac{\partial w_2}{\partial y_2}\right]_{y_2=0}. \quad . \quad . \quad . \quad (5)$$

This condition gives

$$\frac{A_1}{A_2} = \pi\left(\frac{b_1}{b_2}\right). \quad . \quad . \quad . \quad . \quad (6)$$

The stiffener is treated as a compressed flat plate; the elastic strain energy stored due to buckling is

$$U_1 = \frac{1}{2}D_1\int_0^L\int_0^{b_1}\left[\left(\frac{\partial^2 w_1}{\partial x^2}+\frac{\partial^2 w_1}{\partial y_1^2}\right)^2 - 2(1-\nu)\left\{\frac{\partial^2 w_1}{\partial x^2}\frac{\partial^2 w_1}{\partial y_1^2}-\left(\frac{\partial^2 w_1}{\partial x\partial y_1}\right)^2\right\}\right]dxdy, \quad (7)$$

where

$$D_1 = \frac{Et_1^3}{12(1-\nu^2)}, \quad . \quad . \quad (8)$$

in which ν is Poisson's ratio for the material of the panel. Equation (7) reduces to

$$U_1 = \frac{1}{12} D_1 A_1^2 \cdot \frac{m^2\pi^2}{b_1 L} \left[\left(\frac{m\pi b_1}{L} \right)^2 + 6(1-\nu) \right] . \quad (9)$$

An element of the sheet is treated similarly; the elastic strain energy stored in a width b_2 of the sheet between two stiffeners is

$$U_2 = \frac{1}{8} D_2 A_2^2 \cdot \frac{\pi^4 L}{b_2^3} \left[\left(\frac{m\pi b_2}{L} \right)^2 + 1 \right]^2 . \quad (10)$$

During buckling the compression stress σ is assumed to remain constant in magnitude; the external work done during buckling by the end compressions on a stiffener is therefore

$$W_1 = \frac{1}{2} \sigma t_1 \int_0^L \int_0^{b_1} \left(\frac{\partial w_1}{\partial x} \right)^2 dx dy , \quad (11)$$

which reduces to

$$W_1 = \frac{1}{12} \sigma t_1 A_1^2 \cdot \frac{m^2\pi^2 b_1}{L} . \quad (12)$$

Similarly, the work done on an element of the sheet is

$$W_2 = \frac{1}{8} \sigma t_2 A_2^2 \cdot \frac{m^2\pi^2 b_2}{L} . \quad (13)$$

If the number of stiffeners in the panel is large, we may consider a single stiffener and a single breadth b_2 of the sheet as a typical unit of the panel. On the basis of the energy method the stability of this unit is governed by the equation

$$U_1 + U_2 = W_1 + W_2 . \quad (14)$$

On introducing the relation between A_1 and A_2, equation (14) gives for the critical stress, σ_{cr},

$$\frac{\sigma_{cr}}{E} = \frac{\left[\pi^2 \left(\frac{mb_2}{L} + \frac{L}{mb_2} \right)^2 \left(\frac{t_2}{b_2} \right)^2 + \frac{2\pi^2}{3} \cdot \frac{b_1 t_1^3}{b_2^3 t_2} \left\{ \pi^2 \left(\frac{mb_2}{L} \right)^2 \left(\frac{b_1}{b_2} \right)^2 + 6(1-\nu) \right\} \right]}{12(1-\nu^2) \left\{ 1 + \frac{2\pi^2}{3} \left(\frac{b_1}{b_2} \right)^3 \left(\frac{t_1}{t_2} \right) \right\}} . \quad (15)$$

As in the case of most local instability problems, we are interested primarily in the value of m which makes (σ_{cr}/E) a minimum. It is easily shown that the minimum occurs when

$$\left(\frac{L}{mb^2} \right)^4 = 1 + \frac{2\pi^2}{3} \left(\frac{b_1}{b_2} \right)^3 \left(\frac{t_1}{t_2} \right)^3 . \quad (16)$$

Two particular cases of equation (15) are of interest; if $b_1 \longrightarrow 0$, then

$$\left(\frac{\sigma_{cr}}{E} \right)_{min} \longrightarrow \frac{4\pi^2}{12(1-\nu^2)} \left(\frac{t_2}{b_2} \right)^2 , \quad (17)$$

which is the well-known relation for the local buckling stress of a simply-supported flat plate; again, if $t_2 \longrightarrow 0$, then

$$\left(\frac{\sigma_{cr}}{E} \right) \longrightarrow \frac{G}{E} \left(\frac{t_1}{b_1} \right)^2 \left[1 + \frac{\pi^2}{6(1-\nu)} \left(\frac{mb_1}{L} \right)^2 \right] \quad (18)$$

where G is the shear modulus of the material of the panel. The stress is a minimum when $m = 1$; this relation shows that the local instability stress for a compressed plate, simply-supported on one longitudinal edge and free on the other, is always greater than the corresponding torsional buckling stress

$$\sigma_{cr} = G \left(\frac{t_1}{b_1} \right)^2 .* \quad (19)$$

5. An Approximate Treatment of the Torsional Stability of the Stiffeners

As an alternative approach to the problem consider the torsional stability of a stiffener; the angle of twist of the stiffener at any section is

$$\theta = A_2 \left(\frac{\pi}{b_2} \right) \sin \frac{m\pi x}{L} . \quad (20)$$

This is tantamount to assuming that the sheet and the stiffener are rigidly connected along the common longitudinal edge. The elastic strain energy stored in the stiffener during buckling is

$$U_1 = \frac{1}{2} GJ \int_0^L \left(\frac{d\theta}{dx} \right)^2 dx , \quad (21)$$

which reduces to

$$U_1 = \frac{1}{4} GJ A_2^2 \cdot \frac{m^2\pi^4}{b_2^2 L} , \quad (22)$$

where GJ is the torsional stiffness of the stiffener, and is given with sufficient accuracy by $\frac{1}{3} G b_1 t_1^3$. The external work done during buckling by the end compressions on a stiffener is

$$W_1 = \frac{1}{12} \sigma t_1 A_2^2 \cdot \frac{m^2\pi^4 b_1^3}{b_2^2 L} . \quad (23)$$

Consider plate instability of the sheet, as before, and adopt the values of U_2 and W_2 given by equations (10) and (13), respectively. The energy method now gives for the critical stress,

$$\frac{\sigma_{cr}}{E} = \frac{\frac{\pi^2}{12(1-\nu^2)} \left(\frac{mb_2}{L} + \frac{L}{mb_2} \right)^2 \left(\frac{t_2}{b_2} \right)^2 + \frac{2\pi^2}{3} \cdot \frac{G}{E} \cdot \frac{b_1 t_1^3}{b_2^3 t_2}}{1 + \frac{2\pi^2}{3} \left(\frac{b_1}{b_2} \right)^3 \left(\frac{t_1}{t_2} \right)} . \quad (24)$$

This has a minimum value when $(mb_2/L) = 1$; this gives

$$\left(\frac{\sigma_{cr}}{E} \right)_{min} = \frac{\frac{4\pi^2}{12(1-\nu^2)} \left(\frac{t_2}{b_2} \right)^2 + \frac{2\pi^2}{3} \cdot \frac{G}{E} \cdot \frac{b_1 t_1^3}{b_2^3 t_2}}{1 + \frac{2\pi^2}{3} \left(\frac{b_1}{b_2} \right)^3 \left(\frac{t_1}{t_2} \right)} . \quad (25)$$

When $b_1 \longrightarrow 0$,

$$\left(\frac{\sigma_{cr}}{E} \right)_{min} \longrightarrow \frac{4\pi^2}{12(1-\nu^2)} \left(\frac{t_2}{b_2} \right)^2 . \quad (26)$$

agreeing with equation (17); when $t_2 \longrightarrow 0$,

$$\left(\frac{\sigma_{cr}}{E} \right)_{min} \longrightarrow \frac{G}{E} \left(\frac{t_1}{b_1} \right)^2 , \quad (27)$$

agreeing with simple torsional instability theory for a stiffener[2].

*cf. Timoshenko[2].

6. Comparisons with Yusuff's Theory

In the preceding analysis a purely local form of buckling has been discussed first and secondly, a type of torsional-cum-local instability—torsional instability of the stiffeners and local instability of the sheet. In the latter case it is found that

$$\frac{\sigma_{cr}}{E} = \frac{\dfrac{\pi^2}{12(1-\nu^2)}\left(\dfrac{mb_2}{L}+\dfrac{L}{mb_2}\right)^2\left(\dfrac{t_2}{b_2}\right)^2+\dfrac{2\pi^2}{3}\cdot\dfrac{G}{E}\cdot\dfrac{b_1t_1^3}{b_2^3t_2}}{1+\dfrac{2\pi^2}{3}\left(\dfrac{b_1}{b_2}\right)^3\left(\dfrac{t_1}{t_2}\right)}. \quad . \quad . \quad . \quad (24)$$

In his analysis, Yusuff[1] in effect puts $m=1$; this step cannot be justified generally; it has the effect usually of over-estimating the theoretical buckling stress. As shown already, (σ_{cr}/E) is a minimum when $(mb_2/L)=1$. Furthermore, Yusuff ignores the first term of the denominator of equation (24); this is tantamount to assuming that the compression stresses on the ends of the sheet do no work during buckling; this is equivalent to treating the stiffener as elastically supported along its junction with the sheet. On making the two assumptions implicit in Yusuff's analysis, equation (24) reduces to

$$\frac{\sigma_{cr}}{E} = \frac{G}{E}\left[\left(\frac{t_1}{b_1}\right)^2+\frac{1}{4(1-\nu)}\left(\frac{b_2}{L}+\frac{L}{b_2}\right)^2\frac{b_2t_2^3}{b_1^3t_1}\right], \quad . \quad . \quad . \quad (28)$$

which is directly comparable with Yusuff's equation for (σ_{cr}/E).

7. An Alternative Explanation of the Test Results

A number of panel tests are discussed by Yusuff; of these only two compressed panels show local buckling characteristics. The relevant dimensions of the panels are given in Table I, together with the experimental values of (σ_{cr}/E). The values of $(\sigma_{cr}/E)_{min}$, calculated from equations (15) and (24), are also given; for both panels the estimated local buckling stress, given by equation (15), is greater than the torsional-cum-local buckling stress given by equation (24).

The critical stresses given by equation (15) are initial buckling stresses; it is well-known that there may be an appreciable range of post-buckling behaviour if the initial local instability stress of a thin-walled strut is considerably below the proof stress of the material. A study[3] of a large number of experimental results

TABLE I

Test No.	*Relevant Dimensions*				*Values of* (σ_{cr}/E)		
	b_1 in.	t_1 in.	b_2 in.	t_2 in.	From tests	Eqn. (15)	Eqn. (24)
1. (Short Bros. Panel E)	1·055	0·112	2·05	0·050	0·0059	0·0044	0·0036
2. (B.A.C. Panel 1B)	1·45	0·142	2·50	0·100	0·0097	0·0056	0·0044

TABLE II

Test No.	σ_{max} *estimated from equation* (29)	σ_{max} *from tests*
	lb./in.²	lb./in.²
1	59,000	60,000
2	64,000	69,000

suggests that the maximum average compressive stress of a thin-walled light-alloy channel strut is given with reasonable accuracy by the relation

$$\sigma_{max} = 0{\cdot}863\,(\sigma_y{}^2\sigma_{cr})^{\frac{1}{3}}, \quad . \quad . \quad (29)$$

in which

σ_y is the *0·2 per cent.* proof stress of the material,

σ_{cr} is the initial *elastic* local buckling stress.

Unfortunately Yusuff gives little or no information about the material properties of the panels; for the panel tests we assume firstly that E is 10^7 lb./in.²; we then assume that equation (29) is applicable to the problem, and estimate σ_{max} for the value $\sigma_y = 86{,}000$ lb./in.², which is given by Durham and Skaer[4] as a typical tensile 0·2 per cent. proof stress for D.T.D. 683. The estimated values of σ_{max} are given in Table II; they compare not unfavourably with the average maximum stresses mentioned by Yusuff[1]. With well-defined values of E and σ_y, the values of σ_{max} could be estimated more accurately.

Conclusions

It is suggested that the collapse strength of a short panel should be estimated on the basis of the initial local buckling stress and the proof stress of the material; it may be important to allow for post-buckling behaviour if the initial buckling stress is appreciably below the proof stress of the material.

A discussion of the torsional stability of the stiffeners leads to a theoretical buckling stress which under-estimates the 'true' local buckling stress; this would be expected on physical considerations alone.

In a previous analysis of the problem Yusuff[1] makes assumptions which cannot be justified in general; this restricts the usefulness of his method, which may give misleading results if applied widely.

In view of the growing practical importance of integral panels it seems important at this stage to study even more closely the whole problem of local instability; it is possible that a simple solution can be developed on conventional lines. It is clear, however, that more experimental work is required in this field before the problem can be solved finally.

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TECHNICAL NOTES

Contributions to this Section of the JOURNAL *will be eligible for Journal Premium Awards and will normally be published within two months of being received.*

The Pressure Distribution Due to Incidence on a Slender Elliptic Half-Cone

by

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THE SLENDER-BODY solution for the flow about low aspect-ratio wings of non-zero thickness yields a pressure distribution which is valid in the vicinity of the leading edge and therefore suitable for comparison with measured distributions. In this note an expression is derived for the theoretical pressure distribution, due to small incidence, on a slender elliptic half-cone in uniform motion. It is shown that this distribution is additive to the zero incidence pressure distribution. A comparison with some low speed measurements shows qualitative agreement.

The method can be simply extended to other bodies of elliptic cross section.

THEORY

Let Ox, Oy, Os be a right-handed system of rectangular Cartesian body axes such that the equation of the half-cone may be written

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}=s^2 \qquad s\geqslant 0.$$

In accordance with established slender-body theory[1] it is assumed that the velocity potential for the linearised flow past the cone at incidence α has the form

$$\Phi=Us\cos\alpha+U\phi_0+U\phi_1$$

where ϕ_0 and ϕ_1 are harmonic functions of x and y. Here ϕ_0 is the zero incidence perturbation, or thickness, potential and ϕ_1 is the cross-flow potential.

To specify the boundary condition on the cone let C be the cross section of the cone by the plane $s=$ constant and C' the projection on that plane of the cross section by $s+ds$, as in Fig. 1. Then if ν is the distance along the outward normals to C, τ the distance along C and $d\nu$ the distance between C and C', the slender-body boundary condition becomes

$$\frac{\partial\phi_0}{\partial\nu}=\cos\alpha\frac{d\nu}{ds} \quad \text{and} \quad \frac{\partial\phi_1}{\partial\nu}=0 \quad \text{on the cone.}$$

A further boundary condition on ϕ_1 is

$$\frac{\partial\phi_1}{\partial y}=\sin\alpha \doteq \alpha \text{ at a large distance from the cone.}$$

With this notation the quadratic approximation to the pressure coefficient, *i.e.* $C_P=1-(1/U^2)\nabla\Phi\,.\,\nabla\Phi$, becomes, to an appropriate degree of approximation,

$$C_P=\alpha^2-2\left(\frac{\partial\phi_0}{\partial s}+\frac{\partial\phi_1}{\partial s}\right)-\left(\frac{\partial\phi_0}{\partial\nu}+\frac{\partial\phi_1}{\partial\nu}\right)^2-\left(\frac{\partial\phi_0}{\partial\nu}+\frac{\partial\phi_1}{\partial\nu}\right)^2$$

Since on the cone

$$\frac{\partial\phi_1}{\partial\nu}=0 \quad \text{and} \quad \frac{\partial\phi_0}{\partial\tau}=0^*,$$

the pressure coefficient may be expressed as the sum of the zero incidence pressure coefficient and C_{P_1} where

$$C_{P_1}=\alpha^2-2\frac{\partial\phi_1}{\partial s}-\left(\frac{\partial\phi_1}{\partial\tau}\right)^2=\alpha^2-2\frac{\partial\phi_1}{\partial s}-\left(\frac{\partial\phi_1}{\partial x}\right)^2-\left(\frac{\partial\phi_1}{\partial y}\right)^2$$

on the cone.

If $w(x+iy)=\phi_1+i\psi_1$ is the complex potential of the cross-flow, it must satisfy the following boundary conditions

(*i*) $\psi_1=0$ on the elliptic cross section,

(*ii*) $\dfrac{dw}{dx}\longrightarrow\alpha$ as $z=x+iy\longrightarrow\infty$.

The complex potential satisfying these conditions has been given by Milne-Thompson[2] as

$$w=-i\alpha(a+b)s\sinh(\zeta-\xi_0). \qquad (2)$$

the transformation to elliptic co-ordinates ξ,η being

$$z=x+iy=cs\cosh\zeta=cs\cosh(\xi+i\eta) \qquad (3)$$

where $c^2=a^2-b^2$ and on the cone $\xi=\xi_0$, *i.e.* $x=a\cos\eta$, $y=b\sin\eta$.

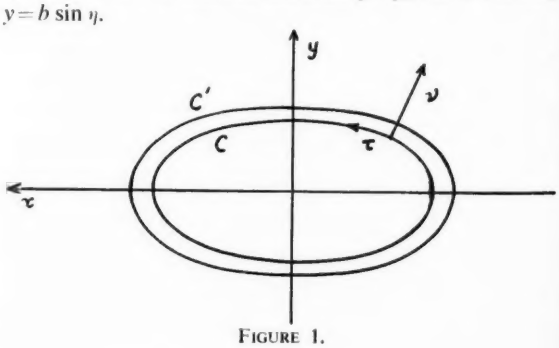

FIGURE 1.

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*The zero-incidence potential may be obtained from the conformal transformation of the flow due to a source. Since the latter is purely radial there will be no circumferential velocity in the transformed plane.

Also[2]

$$\left(\frac{\partial\phi_1}{\partial x}\right)^2+\left(\frac{\partial\phi_1}{\partial y}\right)^2=\frac{\alpha^2(a+b)^2\cosh(\zeta-\xi_0)\cosh(\bar{\zeta}-\xi_0)}{c^2\sinh\zeta\sinh\bar{\zeta}}.$$

On the cone this simplifies to

$$\left(\frac{\partial\phi_1}{\partial x}\right)^2+\left(\frac{\partial\phi_1}{\partial y}\right)^2=\frac{\alpha^2(a+b)^2\cos^2\eta}{a^2\sin^2\eta+b^2\cos^2\eta}. \qquad (4)$$

Taking the real part of equation (2) gives the required velocity potential as

$$\phi_1=\alpha(a+b)s\cosh(\xi-\xi_0)\sin\eta.$$

Thus

$$\frac{\partial\phi_1}{\partial s}=\phi_1\left\{\frac{1}{s}+\xi'(s)\tanh(\xi-\xi_0)+\eta'(s)\cot\eta\right\}.$$

Differentiating (3) partially with respect to s gives

$$\frac{x}{s}=-x\xi'(s)\tanh\xi+x\eta'(s)\tan\eta$$

$$\frac{y}{s}=-y\xi'(s)\coth\xi-y\eta'(s)\cot\eta$$

from which we obtain

$$\eta'(s)=\frac{1}{s}\,\frac{\coth\xi-\tanh\xi}{\tanh\xi\cot\eta+\coth\xi\tan\eta}$$

Thus on the cone:

$$\eta'(s)=\frac{c^2}{s}\,\frac{\sin\eta\cos\eta}{a^2\sin^2\eta+b^2\cos^2\eta}$$

and

$$\frac{\partial\phi_1}{\partial s}=\alpha(a+b)\left\{\sin\eta+\frac{c^2\sin\eta\cos^2\eta}{a^2\sin^2\eta+b^2\cos^2\eta}\right\}$$

$$=\frac{\alpha(a+b)a^2\sin\eta}{a^2\sin^2\eta+b^2\cos^2\eta} \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

Therefore from (1), (4) and (5)

$$-C_{P_1}=2\alpha\frac{a^2(a+b)^2\sin\eta}{a^2\sin^2\eta+b^2\cos^2\eta}+$$

$$+\alpha^2\left\{\frac{(a+b)^2\cos^2\eta}{a^2\sin^2\eta+b^2\cos^2\eta}-1\right\}. \qquad (6)$$

The equivalent result for a cone with incidence α and yaw β can be shown to be

$$-C_{P_1}=2\alpha_1(a+b)\frac{a^2\sin\eta\cos\lambda+b^2\cos\eta\sin\lambda}{a^2\sin^2\eta+b^2\cos^2\eta}+$$

$$+\alpha_1^2\left\{\frac{(a+b)^2\cos^2(\eta+\lambda)}{a^2\sin^2\eta+b^2\cos^2\eta}-1\right\}. \qquad (7)$$

where $\alpha_1=\alpha^2+\beta^2$ and $\lambda=\tan^{-1}\beta/\alpha$.

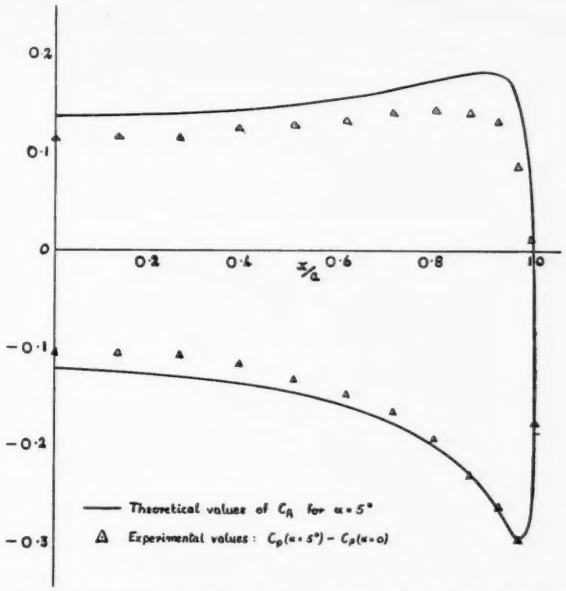

FIGURE 2. A comparison of the theoretical distribution with low speed measurements.

The results (6) and (7) can be deduced from formulae given by Fraenkel[3].

COMPARISON WITH EXPERIMENT

Measurements of the distribution of pressure on a truncated elliptic half-cone have been made in the 5 ft. × 4 ft. low speed tunnel at Imperial College. The cone was 24 in. long with $a=\tan 30°$ and $b=\tan 10°$; the pressure holes were in a plane 8 in. from the apex.

Experimental values of $C_P(\alpha=5°)-C_P(\alpha=0)$ for a wind speed of 100 ft./sec. are plotted in Fig. 2. The full line represents the pressure distribution given by equation (6).

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Notes on a General Method of Treatment of Structural Discontinuities

by

W. J. GOODEY

A STRUCTURE with cut-outs or other discontinuities is generally considered to be more difficult to analyse than a similar structure without such features, although it is in fact less redundant. This is largely due to the special conditions which have to be introduced to allow for these discontinuities, tending to make the calculations less adaptable to routine computation.

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Another and very practical reason is that it is sometimes fairly easy to—dare we say it?—make a reasonable guess at the load distribution in a structure without cut-outs, whereas a much more critical approach is necessary for the treatment of structural discontinuities. Be that as it may, it will be assumed here that the structure without discontinuities, which will henceforth be termed the "original" structure, can be analysed

exactly, in the sense that all the effective redundancies are taken into account. It will now be shown how these calculations may be modified to deal with the corresponding structure with discontinuities, which for this reason will be referred to as the "modified" structure.

If, as will usually be the case, the structure is designed *ab initio* with cut-outs, and so on, these may be filled in with members of any convenient size to complete the "original" structure.

Following Ref. 1, let the strain energy of the original structure be expressed in matrix notation in the form

$$U=\begin{bmatrix}\psi', P'\end{bmatrix}\begin{bmatrix}A, & B\\ B', & C\end{bmatrix}\begin{bmatrix}\psi\\ P\end{bmatrix} \quad . \quad . \quad (1)$$

where $\begin{bmatrix}\psi\\ P\end{bmatrix}$ is the *column* $\{\psi_1, \psi_2, \ldots \psi_j, P_1, P_2, \ldots P_n\}$

the ψ's being the internal redundancies and the P's the applied forces. Dashes denote transposition of columns and rows.

Then the change in U due to small changes in the ψ's is given by

$$dU=2d\psi'(A\psi+BP) \quad . \quad . \quad (2)$$
$$=0 \text{ for minimum strain energy.}$$

If the changes $d\psi'$ are entirely arbitrary, as is the case with the original structure, then $A\psi+BP=0$.

We now imagine the modified structure to be obtained by removing all the bolts or other attachments of the relevant members, this being equivalent to imposing the conditions that the loads in these members shall be zero. This may be expressed by the matrix equation

$$F\psi+GP=0 \quad . \quad . \quad . \quad (3)$$

where F and G are rectangular matrices with as many rows as there are conditions to be satisfied. [NOTE: If there is only a small number of loading cases it is unnecessary to obtain B and G explicitly, it being sufficient to determine the columns BP and GP for each loading case.] Equation (3) implies that some of the ψ's may be expressed in terms of the remainder, which could then be derived from (2) after making use of this relationship. Although the number of equations which have finally to be solved is *reduced*, this method is not necessarily the best for numerical calculations, since the amount of preliminary work required to produce the final set of equations may be considerable. Moreover, unless the matrix F has a particularly simple form, it is by no means obvious which of the unknowns may be most easily eliminated.

The alternative process which forms the subject of these notes makes use of the well-known method of arbitrary multipliers, and although the total number of unknowns is thereby *increased* this is more of a formal than a practical objection, and the method is eminently suited to routine computation.

In view of (3), any set of variations $d\psi'$ must satisfy the conditions

$$d\psi'F'=0. \quad . \quad . \quad . \quad (4)$$

Hence, the expression $d\psi'(A\psi+BP)$ in equation (2) can only be a linear combination of the rows of $d\psi'F'$, *i.e.* $d\psi'(A\psi+BP+F'\lambda)=0$, where λ is a column of numerical multipliers. This is an identity, and so

$$A\psi+BP+F'\lambda=0. \quad . \quad . \quad . \quad (5)$$

Pre-multiplying (5) by FA^{-1} and subtracting (3) gives

$$FA^{-1}BP+FA^{-1}F'\lambda-GP=0,$$

whence $$\lambda=(FA^{-1}F')^{-1}(G-FA^{-1}B)P. \quad . \quad (6)$$

Substitution in (5) then leads to

$$\psi=-A^{-1}[B+F'(FA^{-1}F')^{-1}(G-FA^{-1}B)]P. \quad (7)$$

This is the formal solution of the problem. For numerical work, let (5) and (3) be set out in the form

$$\begin{bmatrix}A, & F'\\ F, & 0\end{bmatrix}\begin{bmatrix}\psi\\ \lambda\end{bmatrix}+\begin{bmatrix}BP\\ GP\end{bmatrix}=0. \quad . \quad (8)$$

These equations may then be solved by the method due to Choleski[2]. The method involves the resolution of the matrix

$$\begin{bmatrix}A, & F'\\ F, & 0\end{bmatrix}$$

into the product (LL') of a lower triangular matrix L, and its transpose, and a somewhat unusual feature here arises from the zero matrix in the bottom right-hand corner. The effect of this is that all the coefficients in the corresponding corner of L, as well as those derived from GP, have a factor $i\,(=\sqrt{(-1)})$. This is somewhat disconcerting at first, but one soon gets used to it, and the process is undoubtedly a most effective way of solving any set of equations with a symmetrical matrix of coefficients.

THE NATURAL MODES AND FREQUENCIES OF VIBRATION OF THE MODIFIED STRUCTURE.

It was shown in Ref. 1 that if the strain energy of a structure is expressed in the form (1), *the ψ's being independently variable*, the quantities $1/\omega^2$ are the latent roots of the matrix $2(C-B'A^{-1}B)m$, where $\omega=2\pi\times$ natural frequency, and m is the diagonal matrix of the masses. In the case of the modified structure, the ψ's are not all independently variable, and the foregoing formula for the natural frequencies is inapplicable. The reason for this is as follows.

If the strain energy is expressed as a function of the applied loads, the deflection (y) of the points of application of these loads are given by the equations

$$y=\frac{\partial U}{\partial P}.$$

If the strain energy is expressed as a function of the applied loads *and* the internal redundancies, then

$$y=\frac{\partial U}{\partial P}+\frac{\partial U}{\partial \psi}\frac{\partial \psi}{\partial P},$$

and it is only when the ψ's are all independently variable that

$$\frac{\partial U}{\partial \psi}=0$$

and the second term in the latter equation for y may be omitted. This was done in Ref. 1, the equation for the frequencies being then derived by expressing the applied loads as inertia forces.

For the modified structure, the simplest procedure is to evaluate (1) as a function of P and λ, making use of equation (5), and then substitute for λ from (6). Thus,

$$U=[\psi',\ P']\begin{bmatrix}-F^{1}\lambda\\ B'\psi+CP\end{bmatrix}$$

$$=(P'B'+\lambda'F)\,A^{-1}F'\lambda-P'B'A^{-1}(BP+F'\lambda)+P'CP$$
$$=P'(C-B'A^{-1}B)P+\lambda'FA^{-1}F'\lambda$$
$$=P'[C-B'A^{-1}B+(G-FA^{-1}B)'(FA^{-1}F')^{-1}(G-FA^{-1}B)]P. \quad . \quad (9)$$

Hence, the quantities $1/\omega^2$ for the modified structure are the latent roots of the matrix

$$2[C-B'A^{-1}B+(G-FA^{-1}B)'(FA^{-1}F')^{-1}(G-FA^{-1}B)]m. \quad . \quad (10)$$

The Choleski process is particularly effective for the computation of the somewhat complicated expression (10), and a convenient arrangement of the work is shown in Fig. 1.

Since the matrix $\begin{bmatrix}A,\ F'\\ F,\ 0\end{bmatrix}$ is symmetrical, the terms below the leading diagonal may be omitted and the space used for the tabulation of the diagonal matrix L, which is here partitioned in the form

$$L=\begin{bmatrix}L_A,\ 0\\ M,\ iR\end{bmatrix}.$$

A similar scheme may be used for the solution of equation (8).

In passing, it may be noted that C, and the two products which follow it in (10), are square matrices of the same order as the number of degrees of freedom of the structure. The computation of the matrices A, B and C is a subject in itself. To some extent it might be described as an art, since considerable freedom of choice in regard to the internally self-equilibrating stress distributions is left to the computer. However, in the present context it is simply assumed that A, B, C, F and G are given. Returning to Fig. 1, the following relationships hold

$$L_AL_A'=A,\quad L_AM'=F',\quad L_AN'=B \qquad \text{and} \qquad MM'-RR'=0,\quad MN'-RS'=G.$$

Hence
$$NN'=B'L_A'^{-1}L_A^{-1}B=B'A^{-1}B,$$
$$RR'=MM'=FL_A'^{-1}L_A^{-1}F'=FA^{-1}F',$$

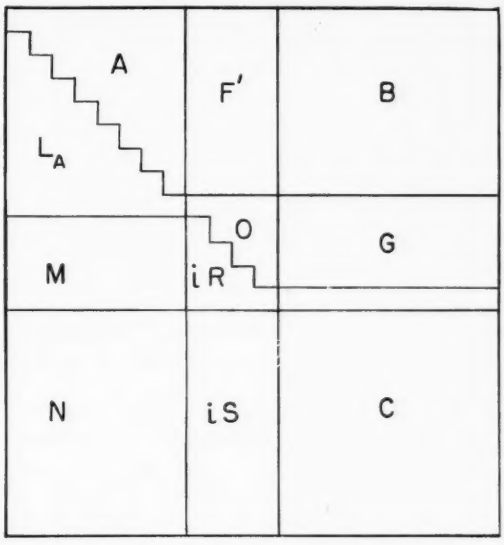

FIGURE 1.

and
$$G+RS'=MN'=FL_A'^{-1}L_A^{-1}B=FA^{-1}B.$$

Then
$$(G-FA^{-1}B)'(FA^{-1}F')^{-1}(G-FA^{-1}B)=SR'(RR')^{-1}RS'=SS',$$

and the expression (10) reduces to

$$2(C-NN'+SS')m. \quad . \quad . \quad (11)$$

The corresponding matrix for the original structure is

$$2(C-NN')m. \quad . \quad . \quad . \quad (12)$$

Note: Since the latent roots of A^{-1} are real and positive, the quantity $\lambda'FA^{-1}F'\lambda$ is positive for any real $F'\lambda$, *i.e.* $\lambda'RR'\lambda$ is positive for any real λ, whence R is real.

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An Approximate Solution of the Laminar Boundary Layer on a Flat Plate with Uniform Suction

by

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NOTATION

- K defined by equation (1)
- R Reynolds Number of flow based on distance along plate from leading edge and U
- U free stream velocity
- v suction velocity at solid boundary
- $\xi\equiv(v^2/U^2)R$
- ρ fluid density
- τ local shear stress at solid boundary
- τ_m mean shear stress at solid boundary

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BOUNDARY layer problems may be divided into two classes: (*a*) those for which similar solutions can be found, *i.e.* where the boundary conditions are such that similar profiles differing only in scale factor exist at different sections; and (*b*) those where the boundary conditions do not effect similarity, so that the development of the boundary layer must be calculated in stages. The latter class are known as "continuation problems," and very few numerical solutions have been obtained because of the labour involved.

Approximate methods of solving continuation problems are known, using the Kármán momentum integral method (*e.g.* Ref. 1) or variants. Some of these methods make use of velocity profiles calculated for "similar" boundary layers. This note presents a new approximate method which uses "similar" profiles but avoids using the momentum integral. Instead of characterising the boundary layer thickness by the "momentum thickness," which needs to be calculated yet is of less direct interest, the wall shear stress is used; this stress usually has to be calculated in any case and the present method is therefore comparatively simple. It is here applied to the flow of incompressible fluid along a flat plate with zero pressure gradient and uniform suction through the surface. The corresponding "similar" boundary layer requires a variation of suction velocity such that $\rho Uv/\tau$ is constant along the plate and values for the local wall stress can be expressed in the form

$$\frac{\rho U^2}{\tau} = \frac{R^{\frac{1}{2}}}{K}. \quad . \quad . \quad . \quad . \quad (1)$$

where K is a function of $\rho Uv/\tau$. The form of the function can be obtained, for example, from the results published by Emmons and Leigh[2].

Differentiating (1) gives an expression for the rate of change of wall shear stress with distance in the flow direction; thus

$$\frac{d(\rho U^2/\tau)}{dR} = \frac{1}{2R^{\frac{1}{2}}K} = \frac{1}{2K^2(\rho U^2/\tau)} \quad . \quad (2)$$

In the continuation problem $\rho Uv/\tau$ is not constant but varies along the surface. The basic assumption of the present method is that nevertheless the rate of change of shear stress with distance depends only on the local values of r, ρ, U, v, (dU/dx), and μ and not on values elsewhere. In the present simple case, ρ, U, v, and μ are uniform; the basic assumption therefore implies that equation (2) holds whether the boundary layer is "similar" or not.

Equation (2) can then be written

$$\frac{d(\rho Uv/\tau)}{(v^2/U^2)\,dR} = \frac{1}{2K^2(\rho Uv/\tau)}$$

The problem therefore reduces to solving, by graphical integration, the equation

$$\int_0^{\xi} d\xi = \int_0^{\rho Uv/\tau} 2K^2(\rho Uv/\tau)\,d(\rho Uv/\tau) \quad . \quad (3)$$

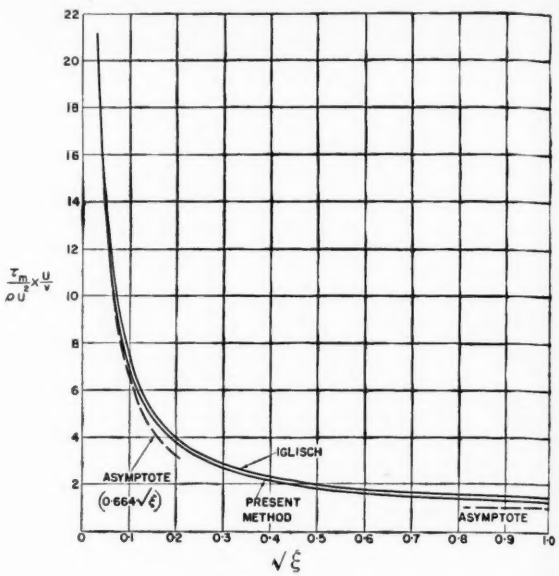

FIGURE 1.

where $\xi = (v^2/U^2)R$ and K, as previously noted, is a known function of $\rho Uv/\tau$. From the resulting relation between ξ and $\rho Uv/\tau$, the local wall shear stress can be found. A second integration (also performed graphically) yields the average wall shear stress in the form

$$\frac{\tau_m}{\rho Uv} = \frac{\int_0^{\xi} \frac{\tau}{\rho Uv}\,d\xi}{\xi}$$

which is plotted against $\xi^{\frac{1}{2}}$ in Fig. 1 for direct comparison with the result of the exact solution of this problem presented by Iglisch[3].

Iglisch does not comment on the accuracy of his results, but these are given to four significant figures and are presumably reliable to about this extent. The maximum difference between the curves representing the results of Iglisch and those of the present method is about 6 per cent. so that the latter may be regarded as satisfactory for most purposes. Also drawn on Fig. 1 is the curve of $0{\cdot}664\ \xi^{\frac{1}{2}}$, which depicts the variation of mean shear stress in the hypothetical case in which suction does not affect the boundary layer velocity profile; the ordinates of the other two curves approach $0{\cdot}664\ \xi^{\frac{1}{2}}$ as ξ tends to zero, and unity as ξ tends to infinity.

Further applications of the approximate method are being studied.

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Instability of Integral Panels

by

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IN a recent article[1] in the Journal Dr. Syed Yusuff complains of a lack of "analytical work on compression panels of integral construction . . . . to provide an insight into the mechanism of the various instabilities involved and also to enable the designer to evaluate its advantages more precisely." It may therefore be pertinent to point out that there is no fundamental difference between the modes of instability of integral panels and those of conventional panels with riveted or bonded stringers, except in so far as certain modes such as inter-rivet buckling cannot arise. Consequently the analyses discussed by Argyris and Dunne in the Handbook of Aeronautics[2] and the more recent paper[3] by Argyris on flexure-torsion panel failure are immediately applicable to integral panels; indeed with an enhanced degree of accuracy due to the monolithic character of the integral panel. Thus, such uncertain factors as the rivet stiffness need no longer be considered. In fact, in the last mentioned paper the analysis is illustrated by application to an integral panel with flanged stiffeners.

Dr. Yusuff then goes on to present an analysis of the flexural-cum-torsional buckling of an integral panel with unflanged stiffeners, the method used being a direct application for this specific geometry of the work of Levy and Kroll[4]. Now it is immediately obvious that for unflanged stiffeners, with an axis of symmetry normal to the plate, there can be no coupling between flexural and torsional modes if the torsion is taken about the line of stiffener-plate intersection. To deduce this by minimising buckling stress with respect to the distance of the axis of rotation is mere mathematical tautology. The lack of coupling is a direct consequence of the symmetry of the stiffener, a fact which is somewhat obscured by the aforementioned minimising process.

The formula developed for the pure torsional case is used to calculate buckling stresses for two test panels and gives a most remarkable numerical agreement with test results. At first sight this appears entirely satisfactory and Dr. Yusuff is led to conclude that his analysis is thus substantiated. However, closer inspection of the theory reveals a number of serious errors and omissions which considerably affect the calculated results.

In the first place, the representation of the restraining effect of the plate on the stiffener rotation as a contribution to the St. Venant torsional stiffness of the stringer, although mathematically adequate, suffers from the disadvantage that it tends to obscure the influence of this restraint on the natural wavelength in the torsional mode. Here the minimum buckling stress is not necessarily associated with a half wavelength (λ) equal to the panel length (or half length for built-in ends)—it need only be an integral fraction of the panel length. Furthermore the form of solution assumed, *i.e.* $\theta=\theta_0 \sin \pi z/\lambda$ is not appropriate for the case of built-in ends since it does not satisfy the boundary conditions, *i.e.* $\theta=d\theta/dz=0$ at the ends. What Dr. Yusuff has really taken here is a solution of the form

$$\theta=\theta_0 (1-\cos \pi z/\lambda)$$

giving quite a different result for the equivalent torsion constant of the sheet from that which he quotes. This error is apparently inherited from the parent work[4] and is presumably due to taking the simple flexural (Euler) case as a model. A much more appropriate model is the strut on a continuous elastic foundation. Ratzerdorfer[5] has dealt with this problem and shows that the actual deflected form when the ends of the strut are built-in is a combination of two sinusoidal waves of different wavelengths which together satisfy the boundary conditions (Fig. 2). The simple Euler form appears as the limiting case of this more general series. Naturally the influence of the end conditions and the panel length become negligible when the natural half-wavelength is small in comparison with the latter. However, for the test panels quoted by Dr. Yusuff this is not the case. In fact, Fig. 4 of Ref. 1 seems to illustrate a twisted shape similar to that illustrated in Fig. 2 (*a*).

A point not mentioned in the paper under discussion is the influence of the direct stress carried in the sheet itself which must seriously affect the restraint provided by the sheet. Parallel with the idea of an effective contribution to the St. Venant torsion constant we may easily take this into account as a contribution (I_p) to the stiffener polar moment of inertia (I_s). With the assumed (sinusoidal) transverse deflected shape we obtain from simple work considerations (*see also* Ref. 3)

$$I_p=b^3t/(2\pi^2)$$

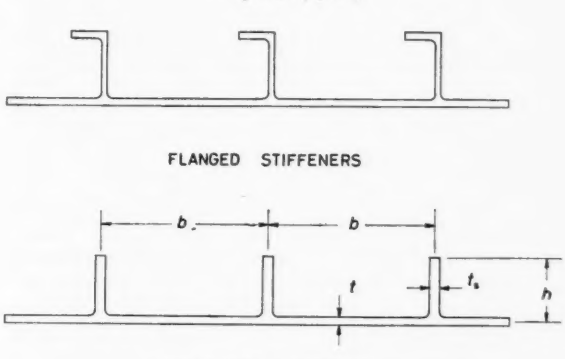

FIGURE 1. Integral stiffeners.

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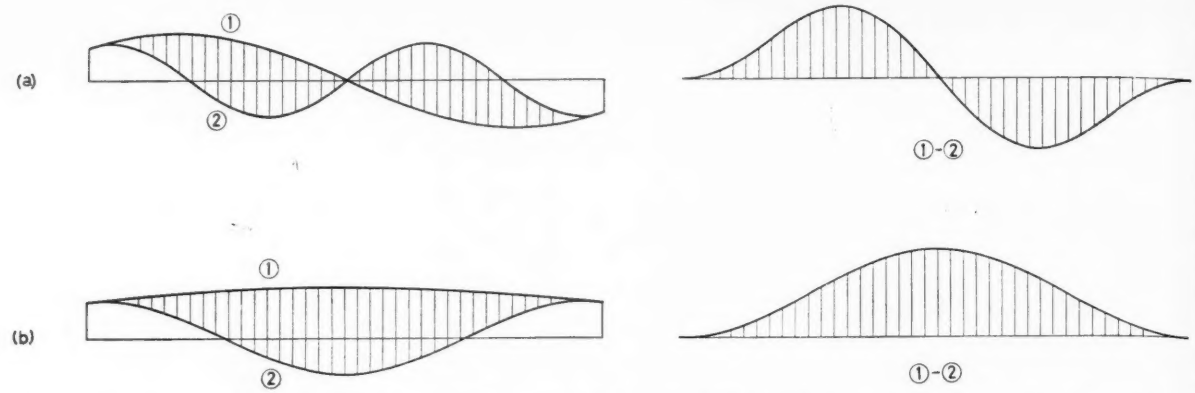

FIGURE 2. Illustrating how the boundary conditions are satisfied at the built-in ends by a combination of two sinusoidal waves of different wavelengths.

Of course, with the more conventional type of formed stringer and comparatively thin sheet, the effect is usually quite small but in the present instance, where the stringer itself has only a small polar moment of inertia, the contribution of the sheet is considerable and cannot justifiably be ignored. Thus in the two panels *E* and 1*B* discussed from the point of view of torsional failure the contribution of the sheet is as much as 50 per cent. of that of the stringer!

Finally, with the sort of stiffener dimensions involved here it becomes necessary to include the secondary torsion-bending constant Γ_2. Calculation shows that its inclusion increases the buckling stress of the two examples considered by approximately 16 per cent. and 7 per cent.

Now all the foregoing points are of fundamental importance and make serious differences to the calculated results. However, much more important is the fact that for the unflanged stiffeners, the torsional mode is nothing more than an approximate representation of the local mode of deformation in which the stiffener displacements consist mainly of rotation. Exact analysis of this case is possible on the basis of thin plate theory and in fact the results of such work have been given by Catchpole[6]. As observed by Dr. Yusuff, buckling in this mode may not necessarily prove critical in the sense of producing immediate failure. Subsequent failure may however occur at a greater stress in essentially the same mode due to the increasing amplitudes of the initial buckles. Naturally the calculation of such a failing load must involve analysis of the post-buckling deformations (also usually in the plastic range) and as yet no suitable theory is available. Nevertheless one would expect only a small margin between initial buckling and failure for panels where, in the initial mode, the stiffener deformation (principally rotation) is restrained by the plate. Referring to Fig. 2 of Ref. 6 such panels are represented in the lower right-hand region of the graph where the curves are concave upwards and the half wavelength is greater than the plate width ($\lambda/b>1$). On the other hand, where sturdy stiffeners are combined with a thin wide sheet so that the stiffener tends to restrain the sheet at local instability, a much greater margin is to be expected before failure.

Examining the two panels discussed by Dr. Yusuff we find that they come into these two separate regions. Thus panel *E* would be expected to buckle initially at a stress of around 36,000 lb./in.² but with the likelihood of a considerable higher failing stress while panel B.A.C. 1*B* has a calculated buckling stress of approximately 60,000 lb./in.² with failure likely to follow quickly after buckling. Actual test results were: Initial buckling at 40,000 lb./in.² with failure at 57,300 lb./in.² in the same mode for *E* and failure at 69,000 lb./in.² for 1*B* with no apparent margin between initial instability and failure. In comparing these results one must bear in mind that the calculated values assume the natural wavelength and wave form to be developed; the restrictions on these due to the short length and the built-in ends of the test panel as discussed previously will naturally increase somewhat the buckling stress. Also the plate thicknesses are not negligible in comparison with width and it becomes arguable, for instance, as to what is the effective plate width. Is it the stiffener pitch or the actual plate width between two adjacent stiffeners? The difference represents about 10 per cent. on buckling stress! Thus the discrepancies are easily accountable—at least qualitatively.

In the light of the foregoing remarks it would appear that the complete agreement claimed by Dr. Yusuff is largely fortuitous as far as the torsional mode is concerned, failure of the panels being due to a development of the initial mode of buckling and not to the sudden appearance of an entirely different torsional mode. It may be of interest that inclusion of the secondary warping constant and the effect of the end load on the sheet and minimisation with respect to wavelength, as discussed above, yield the following formula for the buckling stress:

$$\frac{\sigma}{\sigma_0}=\frac{1}{2}\times\frac{1+2(1-\nu)\left(\frac{h}{b}\right)\left(\frac{t_s}{t}\right)^3+\left\{1+\frac{2\pi^2}{3}\left(\frac{h}{b}\right)^3\left(\frac{t_s}{t}\right)^3\right\}^{\frac{1}{2}}}{1+\frac{2\pi^2}{3}\left(\frac{h}{b}\right)^3\left(\frac{t_s}{t}\right)}$$

where $\sigma_0=3{\cdot}62\,E\,(t/b)^2$

The family of curves represented by this formula is generally similar to the results of the exact analysis (Fig. 2 of Ref. 6) and gives quite good accuracy where the natural wavelength is greater than the plate width. For the short wavelengths however, where the assumed deflected form is quite inappropriate, agreement is very poor. Naturally, since this formula is based on an approximate representation of the displacements, the buckling stress it predicts is always greater than that given by the "exact" local analysis[6]. In any case the formula is of no real practical value since the exact solution is available.

The prediction of failure in cases like panel *E* remains of course a problem. Here, no doubt, the semi-empirical approach will prove useful, but since most integral panels of this type are likely to be designed on optimum considerations to withstand high stresses in the plastic range, it is probable that in most practical cases the margin between buckling and failure will be small.

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Airframe Fatigue

by

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THE JOURNAL in which Mr. W. Tye's Second Barnwell Lecture has been published ("The Outlook on Airframe Fatigue," May 1955 JOURNAL) has now reached Australia. I felt that some comment was called for when I discovered that Mr. Tye had not mentioned the work done in Australia on the life of aircraft structures.

What I believe to be the facts are as follows. Australian concern regarding fatigue was awakened in January 1945, when a Stinson air liner VH-UYY crashed with the loss of ten lives. The analysis made by the C.S.I.R. Aeronautical Research Laboratory confirmed that it was caused by a fatigue failure in the welded tube of the primary wing structure.

Mr. H. A. Wills, in charge of structural and metallurgical research at the Laboratory, initiated a programme of fatigue tests on actual aircraft wings, designed to give factual answers to the problem of determining the safe life of aircraft structures. The basic idea that this could be done had been suggested in a paper by Bland and Sandorf[1], and the Stinson accident provided the necessary urge.

The scale of the experimental work conducted in Australia was substantial and up to the present time has involved ten "Mosquito" wings[2, 3], fourteen "Boomerang" fighter wings[4], and over ninety "Mustang" wings[5], a programme which has just recently been completed. In addition, a study of flight loads was made using *V-g* recorders, while the development of improved statistical instruments was begun, only to be dropped when the counting accelerometer of Mr. Taylor of the R.A.E. was found to be so successful.

While this experimental work was proceeding a theoretical study of the life estimation problem was begun, and this was presented in a lecture by Mr. Wills to the Institution of Engineers, Australia, in September 1947, and subsequently published in their Journal[6]. In retrospect it is interesting to observe that a number of conclusions reached by Mr. Wills in his lecture in September 1947, were arrived at independently about the same time by Mr. H. B. Howard (U.K.) in an unpublished note on "The estimate of the flying life of aircraft parts; a note on the present position" (Dated 12/12/47).

The work of Mr. Wills was not unknown in England, and the Royal Aeronautical Society invited him to give a paper at the Second Anglo-American Conference held in New York in May 1949. This paper[7] was largely based on his earlier paper of 1947 and some of the conclusions are surprisingly similar to those of Mr. Tye, or quoted by him from other and later writers. Mr. Wills pointed out that factors increasing the liability to fatigue failure were "the steady increase in working stresses in wings due to design refinement and to reduction of load factor" as well as "the development of new materials . . . of high ultimate strength . . . . but these high strength materials do not all possess proportionately high endurance limits and they are generally more notch sensitive." He illustrated the method of calculating

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life from the gust load spectrum and the *S-n* data for the wing structure, using the cumulative damage hypothesis, which has been used, sometimes with and sometimes without misgiving, by each successive writer on the subject.

Mr. Wills showed that gust loads of a low order (below load factor 0·5 or a gust velocity of about 6 ft./sec.) could well be ignored in considering fatigue damage; his sample calculation indicated the maximum damage level to be at about 12 ft./sec. gust velocity. Between 1947 and 1949, the fatigue data for the "Boomerang" wings became available, so the 1949 calculation was made using the "initial failure" data for these wings. The sample calculated safe lifetime was 14,900 hours. Who would have expected that two years later a safe lifetime of one-fifth of that figure would be applied to aircraft in service! And how wrong were some of the conclusions of Mr. D. Williams in 1950! (Mr. Tye's Ref. 8).

It is natural that the importance of the Comet and pressure cabin fatigue should have crowded down the space available for accurate and adequate mention of the Dove failures which were first brought into prominence by the fatal accident in Western Australia on 15th October 1951. Suffice to say that a very great deal of work has been done in Australia on the Dove life expectancy, and the first realistic and logical estimate of safe life was made by Hooke[8] and adopted by the Australian Department of Civil Aviation. This is the first time, to our knowledge, that the life of an aircraft was limited for fatigue reasons.

In Australia, the utilisation of aircraft is among the highest in the world and the problem of fatigue life is more pressing than in most other countries. The Department of Civil Aviation is working closely with the Aeronautical Research Laboratories of the Department of Supply to solve this operational problem. To ignore the great contributions which Australians have made to the subject is a manifest injustice to the pioneer work of Mr. Wills and those he has inspired. One may well quote in conclusion the editorial words in *The Aeroplane* of 3rd June 1949 . . . "an outstanding contribution was made to the Conference by an Australian. His country has a population which could be housed in London or New York, yet its aeronautical research establishment has made further progress in the fatigue testing of complete aircraft wings than either the U.K. or U.S.A., an eloquent reminder that achievement comes from selecting the right goal and being single minded in pursuit of it."

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W. TYE

MR. COOMBES' contribution to the subject of fatigue work in Australia gives me an opportunity to attempt to repair any sins of omission in the Second Barnwell Memorial Lecture.

I wholeheartedly support Mr. Coombe's view that Australia has made major contributions in the field of fatigue. My apologies are due to several good friends in Australia, and in particular to Mr. Arthur Wills, if my failure to refer to their work were to be taken as lack of recognition of its value.

In fact, in the extremely brief historical summary of my lecture, I made no attempt to survey the many contributions, and had to content myself with a limited number of references. Since my lecture was in the main for an English audience, I tended to quote notable contributions which had previously had wide circulation in this country.

I must also admit that, although I have had the advantage of discussions with Mr. Wills and others concerned with fatigue work in Australia, I had not seen every one of the references quoted by Mr. Coombes. Possibly this is due to 12,000 miles of separation of our countries; possibly because my own participation in fatigue matters is "part time" and, I hope, temporary. In any event Mr. Coombes has rendered a useful service in bringing myself, and perhaps others, up to date on Australian work.

11th August 1955.

The lobby in the Institute building in Los Angeles.

LOS ANGELES

19th June — 1st July 1955

LONDON TO LOS ANGELES is a long way but 117 British delegates from all parts of the United Kingdom attended the Fifth Anglo-American Conference in California, twenty of them accompanied by their wives. Some had travelled over earlier and made private visits to firms and establishments beforehand; others had arranged to do this when the Conference was over. By Sunday 19th June all had assembled at the Hollywood Roosevelt Hotel in Los Angeles.

Some had already had a foretaste of American hospitality in the Cocktail Party given by Bendix Aviation Corporation the previous evening in New York and the special arrangements made for the "President's Party" aboard the United Airlines Super-Continental DC-7 from New York to Los Angeles. This flight was made non-stop throughout the Sunday and included, among the fascinating changes of scenery across America, a figure-of-eight over Grand Canyon and, from time to time, a commentary from the Captain on special points of interest.

The initial Reception of the Conference, given by the Officers and Council of the Institute of the Aeronautical Sciences, was held on Monday evening 20th June in the Aviation Room of the Hollywood Roosevelt Hotel, and was the first of many pleasant opportunities for the delegates and their wives to meet their American "opposite numbers."

THE LECTURES

From Monday to Wednesday (20th-22nd June), after opening speeches by the Presidents of the Institute of the Aeronautical Sciences and the Royal Aeronautical Society, Mr. Robert E. Gross and Mr. N. E. Rowe, the lectures were held in the Institute building in Los Angeles. Only one hall was in use, so that there were no "duplicate lectures." There were, however, two Chairmen, one American and one English, for each lecture. This was an innovation designed to encourage more easily speakers from both sides of the Atlantic and it seemed to work quite well.

MONDAY 20th JUNE

Morning Session

Opening speeches by the Presidents of the Institute of the Aeronautical Sciences and the Royal Aeronautical Society.

P. G. MASEFIELD (British European Airways): Operating Experience with Turbo-prop Aircraft.

W. C. MENTZER and F. S. NOWLAN (United Air Lines): Airline Use of Elementary Statistical Methods in Aircraft Performance Measurement.

Co-Chairmen:
A. E. Raymond, Vice-President—Engineering, Douglas Aircraft Co, Inc.
S. Scott Hall, Head of Ministry of Supply Staff, British Joint Services Mission.

Afternoon Session

EDWARD H. HEINEMANN (Douglas Aircraft Company): Design of High Speed Aircraft.

BARTRAM KELLEY (Bell Aircraft Corporation): Design of Large Helicopters.

W. S. HEMP (College of Aeronautics): Stress Analysis of Multi-web Boxes.

Co-Chairmen:
C. J. McCarthy, Chairman, Chance-Vought Aircraft Inc.
R. L. Lickley, Chief Engineer, Fairey Aviation Co. Ltd.

TUESDAY 21st JUNE

Morning Session

D. W. HOLDER (National Physical Laboratory): The Interaction Between Shock Waves and Boundary Layers. (Read by Dr. W. P. Jones).

I. I. GLASS and G. N. PATTERSON (University of Toronto): Contributions to Fluid Mechanics from Shock Tube Research.

LESTER LEES (California Institute of Technology): Hypersonic Flow.

Co-Chairmen:
H. L. Dryden, Director, National Advisory Committee for Aeronautics.
Sir Arnold Hall, Director, Royal Aircraft Establishment.

Afternoon Session

R. J. MONAGHAN (Royal Aircraft Establishment): On the Behaviour of Boundary Layers at Supersonic Speeds.

DAVID C. HAZEN (Princeton University): Some Results of the Princeton University Smoke Flow Visualisation Programme.

Co-Chairmen:
Clark B. Millikan, Director, Guggenheim Aeronautical Laboratory.
E. T. Jones, Principal Director, Scientific Research (Air), Ministry of Supply.

Evening Session

P. B. WALKER (Royal Aircraft Establishment): Fatigue of Pressure Cabins.

Co-Chairmen:
Hall L. Hibbard, Vice-President—Engineering, Lockheed Aircraft Corporation.
G. R. Edwards, Managing Director, Aircraft Division, Vickers-Armstrongs Ltd.

Mr. Robert E. Gross, President of the Institute of the Aeronautical Sciences.

Mr. N. E. Rowe, President of the Royal Aeronautical Society.

WEDNESDAY 22nd JUNE

Morning Session

CHARLES F. JOY (Handley Page Ltd.): Some Influences of Equipment Installations and Systems on Aircraft Design.

JOHN W. LUDWIG (Chance-Vought Aircraft Inc.): Power Control Systems for Aircraft.

F. B. GREATREX (Rolls-Royce Ltd.): Jet Noise.

Co-Chairmen:
P. R. Bassett, Vice-President, Sperry Rand Corporation.
Sir A. H. Roy Fedden, Past-President, Royal Aeronautical Society, Aeronautical Consultant.

Afternoon Session

WALTER T. OLSON (N.A.C.A., Cleveland): Combustion for Aircraft Engines.

ADRIAN A. LOMBARD (Rolls-Royce Ltd.): Low-Consumption Turbine Engines.

J. S. ALFORD (General Electric Company): Inlet-Duct Engine Flow Compatibility.

Co-Chairmen:
L. B. Richardson, Senior Vice-President, General Dynamics Corporation.
F. R. Banks, Director, Bristol Aeroplane Co. Ltd.

Evening Session

E. S. MOULT (de Havilland Engine Company Ltd.): Power Plants for Supersonic Flight.

Co-Chairmen:
T. P. Wright, Vice-President for Research, Cornell University.
Hayne Constant, Director, National Gas Turbine Establishment.

These lectures have been reported in the Technical Press, and are to be published in full later in the Conference Proceedings. They were good, solid papers, but the discussions were disappointingly brief, due to shortage of time and not lack of stimulus. There was no doubt plenty of private discussion, over coffee, lunch, tea (iced) and around the swimming pool of the Hollywood Roosevelt, but this cannot be taken as a substitute for the airing of views and posing of questions in public.

The refreshments provided during the days' lectures were excellent. Coffee and tea seemed to be available all the time, there was a small bar alongside the hall, and the lunch arrangements could not have been better, as regards quality, quantity, suitability and service. The number and variety of American salads was a source of wonderment to the "first-timer,"—also of embarrassment, until he had learnt to put a safety factor of a half on what he thought he could easily get through.

There was a 'bus strike on in Los Angeles at the time so that once you had been transported to the lectures at 8.30 a.m. you were there for good, or until the official coach returned at the end of the day. This was not as serious as it sounds, because most of the American delegates had cars and in any case the famous Farmer's Market was within easy walking distance. Here one could spend many an hour loading oneself up with the most exciting things to take home (at a price), only to realise afterwards that they could be divided into three categories, those which were too heavy, those which were too bulky and those which would go bad anyway before you got them home.

While the delegates were indulging themselves at the lectures their wives were being most royally entertained by the wives of members of the Aircraft Industry in Los Angeles. If their days started a little later, they were no less full than those of the delegates. A typical day in the life of a delegate's wife was:—

9.30 a.m.—Leave for TV show.

12 noon—Lunch at the Brown Derby.

2 p.m.—Visit to the Hollywood Bowl or the Greek Theatre.

Evening—Theatre Dinner Party as guests of the Aircraft Industries Association.

The Conference in session in the lecture hall of the Institute building—presided over by a replica of the Wright Brothers' machine.

On the Thursday following the lectures, the delegates themselves had an opportunity of enjoying this rather lighter form of entertainment. They were taken first on a tour of a Movie Studio, then to lunch as the guests of the Lockheed Aircraft Corporation at "Prince" Mike Romanoff's. This lunch was a most splendid affair and at the same time a most friendly one, from which, in the late afternoon, the ladies emerged carrying bunches of red carnations and the tone was already set for the evening's entertainment—the Conference Dinner Dance. It had been arranged for the whole of the British delegation to be taken by taxi to the Hollywood Palladium, and the ladies wore orchids which the Institute had had sent to their rooms. At the dinner, both Presidents made excellent speeches, the I.A.S. Bane and Chanute Awards were presented, and afterwards there was dancing to Harry James's band.

SAN DIEGO

On the next day, Friday 24th June, the whole party made an early start by coach to travel the 140 miles to San Diego, near the Mexican border. During this trip we had our first sight of the Pacific Coast (the centre of Los Angeles is surprisingly some 20 miles from the sea), of orange groves, hibiscus, jacaranda trees and bougainvillea. On arrival at the new Institute building in San Diego, the ladies were taken to lunch at the beautiful home of Mr. and Mrs. R. H. Fleet; after lunch in the I.A.S. building, the delegates began the first of an interesting (if concentrated) series of plant tours, which were to be continued in Los Angeles during the ensuing week.

On Friday evening, after the visits were over, the coaches took both parties by ferry to the Hotel del Coronado in San Diego Bay where, until the next day, they were the guests of the Institute's San Diego Branch, formed mainly from the firms which had been visited during the afternoon. This hotel, built round a courtyard radiant with purple and scarlet bougainvillea and set alongside the Pacific shore, had everything one could wish for—tennis courts, swimming pool, sailing club, games room and ballroom. Flowers were again sent to the ladies, this time from Pan American Airways; they had been specially flown in from Hawaii. At the dinner speeches were made by the Society's President and by the Chairman of the local branch, Mr. E. G. Stout. The dancing session which followed was all too short for some—but perhaps too long for others, faced with another early start the next morning. Some of the party remained in San Diego to accept the hospitality of Solar Aircraft, who had arranged a boat trip round the harbour on the Saturday afternoon, ending up with a cocktail party; others returned in the coaches by an inland route to Los Angeles, breaking the journey with lunch at the beautiful Mission Inn at Riverside. Here, as often during the whole Conference, the skill shown by the Institute's West Coast staff, in transporting a vagrant

Delegates outside the Institute's new building in San Diego.

The front of the Institute's Building in Los Angeles.

and sometimes unpunctual collection of delegates, was most marked.

Returning on the Saturday afternoon to the Hollywood Roosevelt Hotel was like coming home again; but there was scarcely time to turn round and collect the mail—certainly not long enough to take the infinite trouble required to dress up in casual clothes—before setting off again to the Barbecue in Verdugo Park, Glendale. This started with a meal of beef, which had already been roasting in the pits for 20 hours, accompanied by vegetables and salads and followed by ice cream and coffee. Then there was a softball "international"; and some professional "Barber's Shop Quartet" singing later gave way to impromptu choruses, led by the R.Ae.S. President and accompanied on the ukelele by "Doc" Hilton.

Sunday 26th June was nominally a free day, which gave the British delegates the chance of enjoying what is perhaps the greatest pleasure and the most worthwhile part of the whole Conference—private hospitality. If one *can* criticise American hospitality, it is only to say that there should be more chance given to delegates to be able to accept more of it—for certainly much was offered.

THE PLANT VISITS

From the following Monday to Friday (27th June-1st July) the delegates were hard at it again, visiting aircraft plants and research establishments, while their wives were again entertained by the American ladies. The full programme of visits was:—

Friday 24th June

Convair Division of General Dynamics Corporation, San Diego, California, *and*

Mr. Robert Gross speaking at the dinner given at the Hotel del Coronado at San Diego.

The Ryan Aeronautical Co., San Diego, California,
or
The Rohr Aircraft Corporation, Chula Vista, California,
or
Solar Aircraft Co., San Diego, California.

Monday 27th June

{ Douglas Aircraft Co., Santa Monica, *and*
{ Douglas Aircraft Co., El Segundo,
or
{ California Institute of Technology, *and*
{ Aerojet General Corporation.

Tuesday 28th June

North American Aviation Inc., Inglewood,
and either
{ Northrop Aircraft Inc., Hawthorne,
or
{ Marquardt Aircraft Co.

Wednesday 29th June

{ Lockheed Aircraft Corporation, Burbank, *and*
{ Chevrolet Division of General Motors, Van Nuys,
or
{ Zenith Plastics, *and*
{ Harvey Aluminum Division.

Thursday 30th June

Edwards Air Force Base, Muroc.

Friday 1st July

N.A.C.A. Ames Laboratory.

At Convair, delegates saw the R3Y-2 Tradewind turbo-prop seaplane, the Sea Dart, the Model 340 commercial transport, the XFY-1 vertical take-off "pogo stick" and the F102 production line.

The well organised visit to Solar Aircraft included a demonstration of a small hand-started gas turbine engine.

The Douglas Aircraft Company entertained one party of delegates, first at Santa Monica, where they saw the DC-7 production line, the DC-8 fuselage mock-up and the Nike guided missile. After lunch the same party saw the latest military aircraft, the A3D, A4D, F4D and others, at the El Segundo Division. Mr. Donald Douglas, Jnr., welcomed the delegates on arrival and at lunch, and Mr. Ed. Heinemann supervised the plant tours.

Meanwhile on the same day another party visited the California Institute of Technology, where they saw the industrially-owned Co-operative Wind Tunnel and the Jet Propulsion Laboratory. After lunch as the guests of the Aerojet General Corporation the delegates visited the Corporation's plant, where solid and liquid fuel rockets are designed, tested and produced.

On the Tuesday morning, all the delegates went to North American at Inglewood to see the production of Sabres and Super Sabres and in the afternoon the party was again split into two groups. One group visited Northrop Aircraft, where they saw electronic test equipment and the production of the Scorpion interceptor and the Snark pilotless bomber. The other group, after lunch in Marquardt Aircraft's canteen, toured the company's Van Nuys plant, which is concerned with the design and testing of ram-jet engines and afterburners.

(*Below*): The swimming pool at the Hollywood Roosevelt. (*Right*): Mr. and Mrs. N. E. Rowe at the Riverside Mission Inn.

On Wednesday 29th June, half of the delegates visited the Lockheed plant at Burbank, where they saw Super Constellations, fighters and Neptune patrol bombers. Lunch was taken in the Airport Restaurant, as the guests of the Company, and with Mr. Robert Gross presiding. Afterwards this group went on to visit the Chevrolet Assembly Plant.

On the same day, the other half of the party went to the Zenith Plastics Company, where they saw the production of radomes and other plastic components, and then on to the Harvey Aluminum Division for demonstrations of the methods used in the manufacture of aluminium products.

Little more can be said of the details of these visits because most were covered by security. They were all well organised and the British delegates were impressed with the high level of the guides who were appointed to escort them round the various plants. It was usual for a member of the firm concerned to board the coach at the hotel and a short account of the firm's history and a description of what was to be seen was either handed out during the journey or given verbally on arrival. The visitors were often presented with souvenirs in the form of lapel badges, photographs, pens, pencils and models, and each day one of the firms entertained the party to lunch, a particularly happy occasion being the Douglas lunch party at the Del Mar Club overlooking the beach at Santa Monica.

The visit to the Chevrolet plant on the Wednesday afternoon left those who had not seen this sort of thing before quite open-mouthed at the rate at which cars of all kinds were put together and driven off the assembly line—one about every minute or less it seemed. The extreme urgency of every employee was breath-taking, unless one remembered that the labour turnover in this sort of work is very high and that no one person is expected to stick to such a job for long.

During this second week of the Conference, when plant visits occupied the days, there were several evening functions. On the Monday the Aircraft Industries Association (the equivalent of our S.B.A.C.) entertained the whole of the British Party to the dinner-dance and show at Hollywood's "Moulin Rouge." The Los Angeles Branch of the Institute gave a Farewell Reception on the Wednesday evening at their own building in Hollywood where the lectures had been held. Here the British delegates sadly took their leave of their hosts and hostesses of the past ten days; addresses were exchanged and promises made to come again soon ("if I can persuade my boss") and to "look after you when you come to England in 1957 (if you can persuade your boss)." This occasion, more than anything, brought home to us the friendships we had made and what they meant to us.

Early on the Thursday morning the British delegates left by air for Edwards Air Force Base at Muroc, where they inspected aircraft being tested, saw films of the work done at Edwards and, after lunch at the Officers' Club, witnessed a test run at supersonic speed on the N.A.C.A. test sled range. While they were there the temperature reached 98°, and they arrived at Moffett Field next day in a variety of hats and caps not usually seen outside a Christmas party. Thursday night was spent at what is probably the most luxurious motel in the world, "Rickey's Studio Inn," and there was only a short journey the next morning to the N.A.C.A. Ames Laboratory at Moffett Field. This tour, which lasted all day, was most excellently organised and timed, the party being split up into three groups, which visited each of the nine sections in turn. Each talk and demonstration lasted about 25 minutes; in addition the delegates were all given a booklet containing a write-up of the whole visit and of the history of the N.A.C.A.

SAN FRANCISCO

Meanwhile, during the delegates' visit to Muroc and Ames, the ladies had travelled by air from Los Angeles to San Francisco. They were met and looked after by the Institute's San Francisco Branch, taken to tea at the famous Cliff House overlooking the sea and Seal Rocks, and afterwards were driven round San Francisco on a sight-seeing tour. In the evening they set out again by coach, this time for dinner at one of the many delightful fish restaurants on Fisherman's Wharf, finishing up with a grand tour of the City and its bridges by night. On returning late to the hotel in high good humour, many of the ladies were greeted with telephone messages from their husbands who were staying out at Rickey's and who wanted to know how they were getting on.

The Barbecue, Verdugo Park, Saturday 25th June.

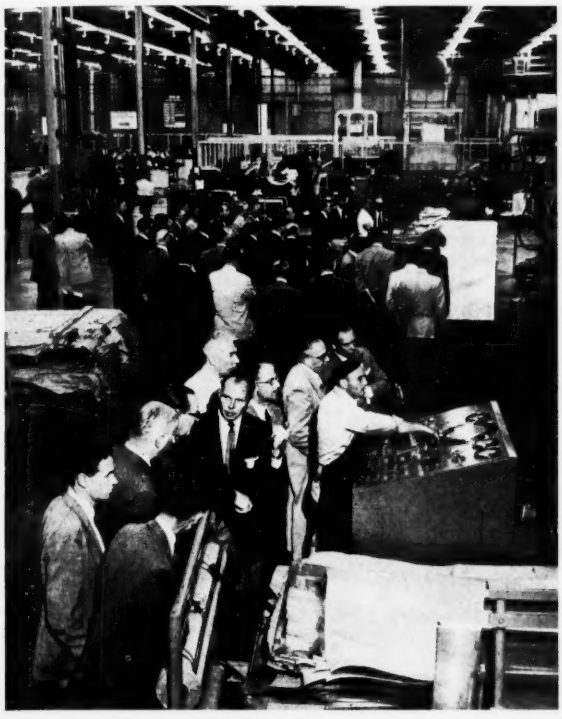
The line-up of Douglas aircraft at El Segundo.

Inspecting an Early Warning Constellation during the Lockheed visit.

The XFY-1 Vertical Take-off " Pogo Stick " at Convair.

Left: The Convair Sea Dart. *Right*: Inspecting the Scorpion at Northrop Aircraft.

The arrangements made for delegates to inspect closely some of the latest American aircraft are worth noting.



A view of part of the shops at North American Aviation, Inc.

Mr. N. E. Rowe, Mr. Edmund Price, President of Solar Aircraft Inc., and Mr. R. H. Weir and the cake which greeted the delegates at tea during their visit to Solar Aircraft.

Inspecting the mock-up of the DC-8 during the visit to Douglas Aircraft Company. Mr. Donald Douglas, Jnr., is in the centre of the group.

Delegates at the Douglas Aircraft Company's El Segundo Plant photographed in front of an A3D Skywarrior carrier-based long-range atom bomber.

H. L. Hibbard and G. R. Edwards as Co-Chairmen during the Technical sessions.

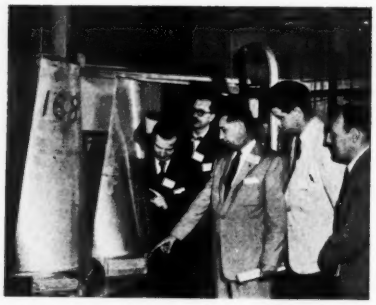
Dr. Hugh L. Dryden, Director of the N.A.C.A., N. E. Rowe, President of the Society, and Dr. Smith J. DeFrance, Director of Ames Aeronautical Laboratory, N.A.C.A., Moffett Field.

S. B. Gates and E. T. Jones.

H. J. Allen, Dr. H. L. Dryden, S. Scott Hall, E. T. Jones and T. James at Ames.

E. W. Robischon, Western Region Manager of the Institute of the Aeronautical Sciences, Los Angeles, and R. J. Monaghan.

F. F. Crocombe, Dr. W. P. Jones and R. C. Morgan at Ames.



H. Giddings, H. F. Vessey, J. L. Parsons, R. J. Monaghan and B. P. Laight at Ames.

Here and There

Sir Roy Fedden, Dr. Ir. A. I. van de Vooren, W. S. Hollyhock, P. G. Masefield and H. J. Allen at Ames.

N. R. Quinn, Dr. E. S. Moult, R. H. Woodall, K. W. Clark and A. A. Lombard at Ames.

R. E. Marquardt and S. Scott Hall and others at the conclusion of the interesting visit to Marquardt Aircraft Company.

Delegates inspecting the test section of the 14-ft. transonic wind tunnel at Ames Aeronautical Laboratory.

S. Scott Hall, Sir Arnold Hall and N. E. Rowe in deep discourse during the visit to North American Aviation Inc.

These messages were variously interpreted by the wives as showing affection, anxiety, or just plain curiosity.

During the ten days that were spent in Los Angeles we had got used to the permanent sunshine and blue skies with a steady temperature around the eighties and nineties, a temperature much easier to bear than in England because of the drier atmosphere, the air conditioning, swimming pools and drinks "on the rocks." We had got used, too, to a sprawling city of over 400 square miles, with mostly low-built impermanent-looking buildings; nearly all Americans admit that Los Angeles is not a "show place."

The change to San Francisco, then, was more marked than it might have been had we gone straight from New York. Everyone had said that we should like San Francisco, and we certainly did. The City has character, it is clean and white and fresh-looking and the beautiful bay and its bridges and hills and harbour and its nearness to the sea give it a charm that Los Angeles could never have. It was a little cooler here, too, and we had a demonstration of the famous San Francisco fog, rolling in from the sea across the Golden Gate Bridge—though most of us, particularly the Londoners, would have called it a sea mist.

On the Friday 1st July the ladies shopped or visited the giant redwoods just north of the City, and in the evening, when the delegates had returned from Ames, the San Francisco Branch of the Institute gave a Farewell Party at the Sir Francis Drake Hotel, where we were staying. This really was the beginning of the end, because now the British party was breaking up and there were those who were going to be back in London by Sunday. Some were going home from New York on the Queen Mary, others to Canada, and a party of 21 were spending the 4th July holiday in Yosemite National Park. By the middle of July practically all the delegates were home again, spending a great deal of their time talking over their experiences, and when they were not talking, they simply fell asleep.

Two of the major impressions of the country as a whole are that the people work harder but live more easily and that their road courtesy is far superior to that in England. But who wouldn't be courteous, when it is so expensive to be otherwise; and it is far easier for a motorist to stop for a pedestrian when all he has to do to regain cruising speed is to take his foot off one pedal and put it on another one, when there are no bicycles or motor cycles to cut across his bows, no slow-moving carts and barrows, no parked vehicles and no veteran cars in the middle of the road to be negotiated. There are other factors which need improvement on the roads of Britain, apart from the roads themselves.

But the greatest impression left in the minds of the British delegates must surely be the overwhelming hospitality and kindliness of the American people. In every city there seemed to be someone who had been forewarned, by someone you had met in the previous city, of your time and place of arrival and who, you had been told, would be "so glad to meet you."

Certainly all who went to the Conference know, and hope the Americans know it too, that when the American delegation arrives for the Sixth Conference in 1957 there will be here in England *at least* 117 people who will be "so glad to meet you again."—E.C.P.

The top table at the Conference Dinner-Dance at the Hollywood Palladium.

ROYAL AERONAUTICAL SOCIETY DELEGATES

Allwright, E. S., Deputy Assistant Chief Designer, Vickers-Armstrongs Ltd.
Ballantyne, A. M., Secretary, Royal Aeronautical Society.
Banks, Air Commodore F. R., Director, The Bristol Aeroplane Co. Ltd.
Barrett, A. J., Technical Assistant (Structures), Royal Aeronautical Society.
Bloch, Lt. Cmdr. R. M., Direction Centrale des Constructions et Armes Navales (Bureau Aeronautique), Paris.
Bloss, H. G., Chief of Aircraft Section, N.A.T.O.
Boswell, A. C., Assistant Designer, Power Plants, The English Electric Co. Ltd.
Brooks, P. W., Technical Assistant to Chief Executive, B.E.A.
Browning, W., Director and General Manager, Saunders-Roe Ltd.
Campbell Orde, A. C., Operations Development Director, B.O.A.C.
Clark, B. F., Project Designer, Boulton Paul Aircraft Ltd.
Clark, K. W., Assistant Director, Directorate of Civil Aircraft Research and Development, Ministry of Supply.
Constant, Hayne, Director, National Gas Turbine Establishment.
Cowdray, C. L., Manager, D. Napier & Son Ltd.
Crabtree, Hedley S., Consultant Engineer, Hedley S. Crabtree & Co. Ltd.
Crocombe, F. F., Chief Engineer, Boulton Paul Aircraft Ltd.
Crowe, F. D., Assistant Chief Designer, Aircraft Production, The English Electric Co. Ltd.
Cuss, J. F., Chief Stressman, Gloster Aircraft Co. Ltd.
Dickinson, R. P., A. & A.E.E., Boscombe Down.
Duddy, R. R., Aero. Flight Section, Royal Aircraft Establishment.
Dunsby, J. A., Technical Assistant (Aerodynamics), Royal Aeronautical Society.
Dykes, J. C., Aeronautical Consultant.
Edwards, G. R., Managing Director, Vickers-Armstrongs Ltd.
Ellis, J. C., Squadron Leader, Royal Air Force.
Fedden, Sir Roy, Aeronautical Consultant.
Fowler, R. G., Chief Aerodynamicist, Folland Aircraft Ltd.
Freestone, Air Commodore L. R. S., British Joint Services Mission in U.S.A.
Gates, S. B., Chief Scientific Officer, Royal Aircraft Establishment.
Giddings, H., Chief Technician, The Bristol Aeroplane Co. Ltd.
Greatrex, F. B., Chief Development Engineer, Installation Division, Rolls-Royce Ltd.
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Holloway, C. F., Technical Adviser, B. P. Aviation Service, British Petroleum Ltd.
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Hughes, S. R., Chief Aerodynamicist, Vickers-Armstrongs (Supermarine) Ltd.
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Russell, Group Capt. H. M., Royal Air Force.
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Still, E. W., Technical Director, Normalair Ltd.
Sutcliffe, P. L., Assistant Chief Aerodynamicist, A. V. Roe & Co. Ltd.
Taylor, J. L., Professor, Tekniske Hoegskdle, Trondheim, Norway.
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Van der Maas, H. J., Professor, Delft Technologist University, Holland.
Van de Vooren, A. I., Chief of Section for Flutter and Theoretical Research, National Aeronautical Research Institute, Holland.
Vessey, H. F., Aero. Flight Section, Royal Aircraft Establishment.
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Waite, P. J., Deputy Division Engineer (Canada), D. Napier & Son Ltd.
Walker, N. K. (in U.S.A.).
Walker, P. B., Head of Structures Department, Royal Aircraft Establishment.
Walmsley, R. H., Head of A.R.G., Ministry of Transport and Civil Aviation.
Ward, R. W., Experimental Designer, Gloster Aircraft Co. Ltd.
Weir, R. H., Principal Director, Engine Research and Development, Ministry of Supply.
Wharton, G. H.
Williams, D. L. Hollis, Technical Director, Westland Aircraft Ltd.
Willit, A. A. J., Pump Designer, Dowty Equipment of Canada Ltd.
Wimpenny, J. C., Senior Aerodynamicist Stability, Control and Flutter, The de Havilland Aircraft Co. Ltd.
Woodall, R. H., Technical Director, Rotax Ltd.
Youens, F. P., Advanced Projects Engineer, Short Brothers & Harland.

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Reviews

THE SCIENCE OF PETROLEUM, VOLUME V. PART III. REFINERY PRODUCTS. *General Editors: B. T. Brooks and A. E. Dunstan. Oxford University Press, Geoffrey Cumberlege, London, 1955. 397 pp. Illustrated. 126s.*

Part III, Refinery Products completes Volume V of *The Science of Petroleum*; Part I appeared in 1950 and Part II in 1953. The original purpose of this volume was to record development in the science during 1937-1947, and in this particular book developments in the manufacture, analysis and testing of automative fuels, lubricants, waxes and other Refinery Products are described, together with the application of more specialised techniques, such as X-ray, Infra-Red, Mass and Raman Spectroscopy to Hydrocarbon Analysis. The book contains 23 chapters dealing with: The Manufacture and Testing of Aviation Fuels; Gas Turbine Fuels; Motor Gasolines in the U.S.A. since 1937; Knocking Characteristics of Hydrocarbons; Improvement of Diesel Fuels; Lubricating Oil Addition Agents; Boundary Lubrication; Paraffin Wax; Microcrystalline Waxes; Petroleum White Oils and Sulphonic Acids; Analytical and Testing Methods; Engine Testing Lubricating Oils; Laboratory and Small Scale Distillation; Viscosity-Temperature-Pressure Relationships of Petroleum Products; Nitrogen Tetroxide Method for the Determination of Olefinic Unsaturation; Volume and Specific Gravity Corrections for Petroleum Oils; X-Ray Examination of Hydrocarbons; Magneto-Optical Rotation of Hydrocarbons and their Mixtures; The Application of the Infra-Red Absorption Spectra to the Study of Petroleum Derivatives; Application of Infra-Red Spectroscopy in the Petroleum Industry; The Mass Spectrometer in Hydrocarbon Analysis; Raman Spectroscopy in the Petroleum Industry.

As in previous volumes each chapter is written by a specialist, or specialists, in the particular subject and represents an authoritative review of the development and status of a particular subject up to the end of 1947. In some instances the authors have taken advantage of delays in publication to include reference to work as late as 1950. Certain of the chapters contain information which has not previously been published, or at least which is collected together in chapters for the first time. Of particular interest are the chapters dealing with the manufacture of aviation gasoline and turbine fuels. The historical background to the manufacture of aviation fuels given by W. A. Partridge will recall for many the excitement and difficulties of the early years of the war and will be read with interest and appreciation by all who were concerned with this problem. The chapter on the Knocking Characteristics of Hydrocarbons reviews the available knowledge on this subject, collected from the data published by A.P.I. Project 45 and the publications of the National Advisory Committee of Aeronautics (U.S.A.), and presents in tabular form the whole of the data on pure hydrocarbons, together with details of the test conditions and so on. These results are used to present graphically (in 44 figures) a variety of relationships between knocking characteristics, hydrocarbon structure, effect of tetra-ethyl lead and so on.

The rapidity of development of analytical procedures within the Petroleum Industry is shown by the extensive account given by W. H. Thomas of developments during 1938-1952 and by J. G. Withers in the Development of Engine Testing of Lubricating Oils. Developments in Spectroscopy have been so marked during the past five years as to make obsolete much of the equipment described in the chapters dealing with these subjects. Nevertheless the data presented on the spectra of hydrocarbons remains of value.

The Editors have had many difficulties to overcome in the completion of their original task, and probably they will question the desirability of extending the Science of Petroleum to further volumes covering advances in the next ten years (1950-1960). It is to be hoped that this will be done and that every effort will be made to produce subsequent volumes as soon as possible after the end of the period to which they refer.

The present book is, like its predecessors, excellently produced, well indexed and clearly illustrated. Despite the delay in publication it remains an authoritative treatise on the Science of Petroleum.—F. MORTON.

PRINCIPLES OF ENGINEERING THERMODYNAMICS. *Paul J. Kiefer, Gilbert F. Kinney and Milton C. Stuart. Second Edition. John Wiley & Sons, New York, 1954. 539 pp. 62s.*

Although described as a second edition this textbook has in fact been very largely re-written, and its scope has been materially widened. It deals more than adequately with all the theoretical aspects of thermodynamics that are likely to be encountered by candidates for an honours degree in engineering. About two-thirds of the material is devoted to a detailed study of basic thermodynamics, and of the properties of gases and fluids. The remainder deals with the engineering applications of these principles, but throughout the emphasis is on principles rather than practice.

This is in accordance with the authors' policy. They declare their conviction "that the real purposes of engineering education are better served by careful considerations of the fundamentals of a science such as thermodynamics rather than by cursory and superficial attention to numerous specific applications." It may be said at once that this book is firmly based on that declaration, and a sincere attempt has been made to ensure a full understanding of the fundamentals of the subject. One criticism might in fact be that their desire to clarify a point by alternative presentations has occasionally led the authors into complicated, almost legalistic, forms of words. These sometimes obscure the point instead of achieving the object, but it is at least refreshing to find a thermodynamics textbook in which explanation of some of the real dificulties is attempted.

Part III, which deals with the Properties of Fluids, is particularly well presented, and the section dealing with gas-vapour mixtures is a model of clarity.

The brief chapter on combustion calculations could well be extended, and the discussion of power generation cycles is also, in the reviewer's opinion, unduly restricted.

In general this book may be recommended for engineering degree students, and in particular for those with leanings towards mathematics.—H. BILLETT.

GAS TURBINES II: SOME FUNDAMENTALS OF COMBUSTION. *D. B. Spalding. Butterworths Scientific Publications Ltd., 1955. 249 pp., illustrations. 40s.*

Despite the abundance of literature on combustion, it is no easy task to select a small number of textbooks which, studied in turn, will lead the aeronautical student logically through the subject up to the more advanced aspects of continous-flow combustion. Most textbooks on gas turbines follow a set pattern, and include a useful, but necessarily brief, chapter on combustion which can serve as an introduction. The student is then left to flounder through a mass of articles and symposia, mostly of a highly specialised nature. The appearance of Dr. Spalding's book, therefore, is very welcome indeed, and its value to the student is of immediate interest.

The book opens with a review of essential thermodynamic data, followed by a chapter on the concepts of fluid flow. Both are very clearly presented and neatly balanced, the explanation of the compressible flow chart, for example, being first class. The following two chapters deal with the transfer of mass and heat, which the author has studied for many years at Cambridge University. These chapters serve as an excellent survey of current thought, the relevant theories and conclusions being presented and their significance outlined. The reader is able to gain a clear picture of present knowledge, and to follow the author's own arguments throughout the chapters. Examples included judiciously in the text serve to drive the points home. The fifth chapter, on the chemical effects in combustion, deals mainly with flame propagation, stabilisation, and instability, and the final chapter discusses the many engineering applications of the principles covered.

The use of the first person plural is probably not universally acceptable for a textbook, and the titles of Figs. 5.5 and 5.42 need attention. A symbol " I " appears to be missing from Fig. 2.9, but the illustrations are generally bold and clear, in typical Butterworth style. An adequate index is provided, but a more detailed contents list would have enabled the reader to plunge into each chapter with a knowledge of the terrain ahead, and saved the need for occasional signposting. A bibliography is included after each chapter, and a list of some 200 references at the end of the book. The symbols used are designated at the end of each chapter, and this seems to support the growing feeling for greater standardisation.

The book summarises and categorises the numerous steps forward that have been made towards the true understanding of combustion processes and, therefore, is itself an advance in this direction. Combustion processes are analysed and made amenable to mathematics, the assumptions made being stated in each case, and the whole is presented in a very readable manner. The book will prove of undoubted value to the practising gas-turbine designer and combustionist, and will do much to ease the load of students and teaching staff alike. Inevitably different readers would like to see different aspects of the subjects included and others enlarged: the title itself acknowledges this. One is tempted to ask for more on dissociation, spontaneous ignition, detonation, instability, scaled combustion, etc., in the same lucid style, although these points are all mentioned and their significance outlined. While accepting with gratitude this contribution to the literature, one looks forward with interest to the forthcoming companion volume on combustion practice.—E. M. GOODGER.

THE FLIGHT OF ALCOCK AND BROWN. *Graham Wallace. Putnam, London, 1955. Illustrated. 312 pp. 18s.*

Mr. Wallace is a writer and director of documentary films, and he presents his account of the first Atlantic flight as a documentary report. The reader is not taken out of his chair into the cockpit of the Vickers *Vimy*, as he is into the *Spirit of St. Louis* in Lindbergh's story of the first solo transatlantic crossing. He remains an observer before whom the events are unfolded.

Occasionally intrusion of screen technique—the flash-forward and the flash-back, the cut to a different " camera angle "—makes the narrative jerky and repetitious, and in places there is an overweight of detail.

These are minor criticisms, however, that should not deter anyone from reading this saga of courage and endeavour in the adolescent stage of flying. The Atlantic flight of Alcock and Brown, two former prisoners-of-war brought together by last-minute chance, marked the beginning of an era of pioneers flying into the unknown, to open up the air lanes of the world. It was a period when achievement depended upon the initiative, imagination, and resource of the human individual. The pilot was not then an instrument of science to be propelled by efficient mechanical means.

The details of the difficulties that Alcock and Brown had to overcome in Newfoundland make stirring reading. Their chances of being first across the Atlantic and winning the £10,000 prize looked remote. Only bad weather was holding up Hawker in the *Atlantic*, and Raynham in the *Raymor*, while they still awaited the shipment of the *Vimy* from England.

Hawker's failure in mid-Atlantic and Raynham's crash on take-off put them back in the running, but they could find no suitable site for an aerodrome. Raynham, who was repairing his machine for another attempt, sportingly gave them the use of his field for assembly and initial testing. It was not long enough, however, for the *Vimy* to take off with full load, and finally trees had to be felled, boulders dynamited, and dykes filled, to turn " Lester's Field " into a suitable base.

When the *Vimy* was ready for the flight another setback occurred. The rubber compound lining their fuel storage drums had dissolved into the petrol. Again Raynham came to the rescue and offered them his own fuel as they needed it before he did.

That, perhaps, signified as much the spirit of the period as the flight of sixteen hours, twelve minutes, across, in Winston Churchill's words, " that terrible waste of desolate waters, tossing in tumult in repeated and almost ceaseless storms . . . and at every moment liable to destruction from a drop of water in the carburettor, or a spot of oil on their plugs, or a tiny grain of dirt in their feed pipe, or from any of the other hundred and one indirect causes which in the present state of aeronautics might drag an aeroplane to its fate."—EDWARD LANCHBERY.

CONTROL CHART TECHNIQUE, WHEN MANUFACTURING TO A SPECIFICATION. *B.S. 2564: 1955. British Standards Institution. 80 pp. Diagrams. 10s. 6d.*

This booklet describes, with examples, the construction and use of quality control charts, with special reference to articles machined to dimensional tolerances. It is intended to supplement, by showing the practical application and giving examples, the existing British Standards (B.S. 600 and B.S. 600R) on Quality Control. The information is in two parts, dealing respectively with quantitative and qualitative data, and there are Appendices containing

definitions, comments on sampling procedure, on the sensitivity of control test schemes and on low relative precision.

TECHNICAL PUBLICATIONS—THEIR PURPOSE, PREPARATION AND PRODUCTION. *C. Baker. Chapman and Hall Ltd., 1955. 302 pp. Illustrated. 36s.*

This book meets a need that has become acute only recently and meets it well. During the present century the bulk of technical material that is printed, cyclostyled or typewritten has increased vastly. If the rising tide of paper that threatens to swamp many of our offices appears sometimes as an evil, it has to be recognised as a necessary one. The written word has come to be one of the more important tools on which modern industry depends. Like all tools this one must be adapted to its purpose. The many persons who nowadays spend a substantial fraction of their time writing, distating or reading have to become as conversant with the techniology of the written and printed word as with the other technologies that they encounter in their professional work.

The textbooks that are designed to serve this purpose are still all too few. The integrated effort that has to be made in order to produce a technical publication has not yet come to be recognised in its full scope. The book under review is a welcome addition to the existing slender library in this field.

After a description of the principal forms of technical publicity there is a chapter entitled "Meeting the User's Needs" followed by chapters on "The Use of Words" and on "Copy Writing." These occupy between them about a third of the book. The remainder deals with practical technicalities, such as illustrations, methods of reproduction, preparing copy for the press, proof correcting, the printer's activities, the collection of information, legal documents. The earlier third of the book is perhaps the least successful, but the author can hardly be blamed for this. No one has yet quite succeeded in solving the problem of giving guidance to the author of technical literature. In America sundry attempts have been made to devise a formula. Count the average number of syllables in a word, it is said, and the average number of words in a sentence and subject the result to an algebra that gives a quantitative assessment of readability. Such advice might be entitled "How to Write Without Taking Thought." Unfortunately, it cannot be done that way. Instruction in what is called "English" in our schools and universities again is a little better but hardly relevant to the real problems. The book under review does attempt at least to emphasise those problems that the author should take thought about. It gives often quite striking examples of good and bad writing. But I doubt whether a reader of this book would be able to generalise from those examples and recognise cases where the advice given applied to his own problems.

The remainder of the book deserves nothing but praise. The examples of line drawings and diagrams of connections are so given that they do lead to useful generalisations. The good and bad ways of drawing the same electric circuit diagram, as illustrated on pages 136 and 138, is most striking. The good way shown there has long been advocated by that eminent scientist who has adopted the nom de plume "Symbol Simon." The chapter on techniques of reproduction gives exactly the type of information that is so useful for the head of any big office. Similarly, in other chapters exactly the kind of sound advice and interesting information is provided that will be helpful to those who want to deal as efficiently with their mass of paper work as they do with their scientific work.—REGINALD O. KAPP.

NUMERICAL METHODS. *A. D. Booth. Butterworths Scientific Publications, 1955. Illustrated. 195 pp. 35s.*

In the relatively small compass of 190 pages, Dr. Booth has brought together a wide variety of topics of interest to users of digital computing machines. Chapters are devoted to The Nature and Purpose of Numerical Analysis; Tabulations and Differences; Interpolation; Numerical Differentiation and Integration; The Summation of Series The Solution of Ordinary Differential Equations; Simultaneous Linear Equations; Partial Differential Equations; Non-linear Algebraic Equations; Approximating Functions; Fourier Synthesis and Analysis and Integral Equations. The inclusion of several items which have not, so far as the reviewer is aware, been gathered together before in a work of this nature could have helped to make this an excellent introduction to the subject but unfortunately, in addition to the omissions that inevitably follow such compression, the material presented contains numerous errors ranging from trivial details to more serious errors in formula or method.

In order not to obscure the underlying mathematical basis of the work, Dr. Booth has deliberately eschewed reference to the detailed form of calculations. Often however, it is just these details that decide the success or failure of a computational method, whether the calculations are to be carried out on desk machines or high-speed automatic computors.

Although the style is in general clear and readable there is evidence of the book having been put together hurriedly and many of the errors would have been exposed by actual calculation based on the methods proposed. Thus although on page 88 it is stated that it is easily shown that the magnitude of the greatest latent root of AA' is equal to the square of the modulus of the greatest latent root of A, this is in fact untrue; nor will workers in the aeronautical field derive much solace from the suggestion that most large matrices occurring in practice are symmetrical. The reader must also be warned of the error occurring in the formula for the first derivative appearing on page 30, and repeated on page 114, in which the coefficient of the seventh difference should be 1/140. Also the treatment of errors in this chapter is based entirely on derivatives, which can be very misleading.

The treatment of references is strangely selective; in particular one notices the omission of any reference to Fox's work on relaxation methods or to Gill's programming of the Runge-Kutta method of integration for differential equations, a model example of the art.

Finally, having regard to the size of the book, the price of 35/- seems unduly high.—E. T. GOODWIN.

BIRD MAN. *Léo Valentin. Hutchinson, 1955. 127 pp. Illustrated. 12s. 6d.*

During a free fall from 9,000 to 3,000 feet in May 1954, Léo Valentin glided three miles on wooden wings attached to his body by a tubular steel corset. "I was the first man ever to have flown," he proclaims.

The wings are plywood with internal strutting. There are grooves for his arms behind the leading edge, and rudder controls at the tips. They can be fully extended in the flying position or folded back, and the whole apparatus weighs 28 lb.

Monsieur Valentin sees in their development the possibility of a number of parachutists leaving an aircraft

together, but gliding to land at different points over a wide area "where not even helicopters could venture."

Although these wings give the book its title, "Bird Man," the greater part of the story deals with the author's adventures as a stunt parachutist. He berates his own country for disinterest in popularising parachuting, but his argument on behalf of free falls as a sport is unconvincing and fails to communicate whatever fascination there may be in this activity.

His case is not helped by a style lavish with clichés and often naive. In the air: "I clutched on to my liftwebs like grim death." On the ground: "I don my terrestial nature once more."

He comments on aircraft design: "The plane is supported by suction, by a depression above, and not lifted by pressure below. That is why designers place the undercarriage .... beneath the fuselage."—EDWARD LANCHBERY.

TRANSACTIONS OF THE SYMPOSIUM ON COMPUTING, MECHANICS, STATISTICS AND PARTIAL DIFFERENTIAL EQUATIONS. *Interscience Publishers Inc., New York, 1955. 216 pp. $5.00.*

This volume is a collection of the papers delivered at a Symposium in Applied Mathematics, held in Chicago in April 1954 and sponsored by the American Mathematical Society, and the Office of Ordnance Research of the U.S. Army. A wide range has been covered, the papers dealing with recent advances in such branches of mathematics as operations research, statistics, computation, and partial differential equations.

Some papers, such as those on operations research and numerical computation, are very general, outlining the methods and uses of the fields concerned. Others deal with more specific problems, such as that of the homogeneity of neutral V-particles which is used to illustrate the general ideas in the paper on Inductive Inference, and the Cauchy problem for the wave equation and the equation of damped waves which is considered in the paper on Divergent Integrals and Partial Differential Equations.

Other papers discuss such varied subjects as recent developments in two aspects of Analysis of Variance, Iterative Computational Methods particularly as applied to matrix problems, the Stability of Mechanical Systems, and the use of generalised differential operators with a brief mention of lateral conditions in general.—M.E.M.

CIVIL AIRCRAFT MARKINGS. *J. W. R. Taylor. Ian Allan (abc series), 1955. 75 pp. Illustrated. 2s. 6d.*

This booklet is different from others so far received here in that it lists the registrations of British aircraft correct to February 1, overseas airline fleets using this country, some military charter serials and M.o.S. test aircraft numbers. There is also a note on military registration numbers with a *dreadful warning* to embryo collectors. The frequency with which these booklets and their revised editions appear is quite astounding and now that Mr. Taylor is devoting all his time to such projects one wonders if they will have to be treated as periodicals. —F.H.S.

BRITISH CIVIL AVIATION. *D. G. T. Harvey. Adlard Coles, Southampton. 168 pp. Photographs and diagrams. 15s.*

It must be increasingly difficult for the authors of "identification" books to find fresh excuses for putting them together and new titles when they have been put together. Mr. Harvey had the additional difficulty of trying to include aeroplanes "on the stocks." As a result, a machine like the *Accountant* or the *Herald* has to be given as an "artist's impression" which looks quite out of place in this type of book.

Sections 5 and 6 (The Operating Companies and Personnel) are certainly a departure from the usual run of identification books and present, in handy and easy-reference form, particulars of 32 operators in this country and information about the little people who "make the wheels go round."—F.H.S.

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Boundary Layer

The boundary layer with distributed suction. M. R. Head. R. & M. 2783 (*April* 1951, *published* 1955).

Experiments performed in flight at Reynolds numbers in the region of 3×10^6 have clearly demonstrated the stabilising effect of small amounts of distributed suction on the laminar boundary layer. In the absence of a pressure gradient and in adverse gradients similar to those occurring on a normal aerofoil, transition of the boundary layer to the turbulent form has been prevented by the use of such suction quantities as may be expected to lead to very considerable reductions in effective drag. It appears, however, that for extensive laminar flow to be achieved in this way, the surface must be free from such excrescences as would cause transition in the absence of suction. Laminar boundary-layer velocity-profiles obtained with suction in the absence of a pressure gradient are found to be in good agreement with those calculated for the flat plate, and the suction quantities required to maintain laminar flow are similar to those suggested by stability theory.—(1.1.5.1).

An experimental investigation of the boundary layer on a porous circular cylinder. D. G. Hurley and B. Thwaites. R. & M. 2829 (*July* 1951, *published* 1955).

An experimental investigation of the boundary layer on the surface of a porous circular cylinder is described at which there is a normal inward velocity. Owing to practical difficulties in the exploration of the very thin boundary layers and in the determination of the velocity gradient around the surface, other comparisons with the theory (such as the progressive development of the boundary layer velocity distribution and of the prediction of the separation point) were difficult. Nevertheless, reasonable agreement between the theoretical and experimental velocity distributions was obtained, particularly for the lower wind speed of the experiment, but no adequate test of the prediction of the separation point was found possible.—(1.1.5).

Wind-tunnel tests on the NPL 434 nose-slot suction aerofoil. J. Williams, R. C. Pankhurst and Edna M. Love. R. & M. No. 2876 (*March* 1952, *published* 1955).

Stalling tests were made on the 8 per cent. thick section N.P.L. 434, which has been specially designed for nose-slot suction. At the higher suction quantities, the maximum lift of the aerofoil was considerably greater than for the Lighthill and Glauert sections previously tested when due allowance was made for the difference in camber. At low suction quantities there was no improvement.—($1.1.5 \times 1.10.2.1$).

Analysis of two-dimensional compressible-flow loss characteristics downstream of turbomachine blade rows in terms of basic boundary-layer characteristics. W. L. Stewart. N.A.C.A., T.N. 3515 (*July* 1955).

Equations are derived for obtaining compressible-flow boundary layer characteristics for a simple power velocity profile. Loss coefficients at the trailing edge and after mixing are then obtained in terms of these boundary layer characteristics. This analysis is used to study the general effect of compressibility on blade exit loss characteristics, the significance of mixing downstream of the blade row, and the effect of trailing-edge thickness on overall loss coefficients.—($1.1.0 \times 1.4.1$).

A study of boundary-layer transition and surface temperature distributions at Mach 3·12. *P. F. Brinich. N.A.C.A., T.N.* 3509 (*July* 1955).

Surface temperature distributions and high-speed schlieren motion pictures were used to study transition with and without single roughness elements on a hollow cylinder at various wind tunnel Reynolds numbers.—(1.1.2.4).

Compressible Flow

A note on the sound from weak disturbances of a normal shock wave. A. Powell. A.R.C., C.P. No. 194 (1955).

The disturbances of a shock wave by sound waves or temperature fluctuations is studied in one dimension to a first order approximation. In general, both sound waves and temperature fluctuations arise behind the shock wave. Expressions are given for their amplitudes, and calculated for $M = 1{\cdot}4$. Sound waves colliding with the shock wave are amplified, but sound waves are almost annihilated by weak shock waves if originally travelling in the same direction as the shock wave. Small temperature fluctuations give rise to much sound, on an acoustical scale.—(1.2.3.2).

The theoretical wave drag of some bodies of revolution. L. E. Fraenkel. R. & M. 2842 (*May* 1951, *published* 1955).

The wave drag is investigated of bodies of revolution with pointed or open-nose forebodies and pointed or truncated afterbodies. The "quasi-cylinder" and "slender-body" theories are reviewed, a reversibility theorem is established, and the concept of the interference effect of a forebody on an afterbody is introduced. The theories are applied to bodies whose profiles are either straight or parabolic arcs, formulae and curves being given for forebody and afterbody drag, and for the interference drag. The results of the two theories are compared and are seen to agree well in the region of geometries where both theories are applicable.—(1.2.3).

A low-density wind-tunnel study of shock-wave structure and relaxation phenomena in gases. F. S. Sherman. N.A.C.A., T.N. 3298 (*July* 1955).

The profiles and thicknesses of normal shock waves of moderate strength were determined in terms of the variation of the equilibrium temperature of an insulated transverse cylinder in free molecule flow. The shock waves were produced in a steady state in the jet of a low-density wind tunnel at initial Mach numbers of 1·72 and 1·82 in helium and 1·78, 1·85, 1·90, 1·98, 3·70, and 3·91 in air.—(1.2.3.2).

Maximum theorems and reflections of simple waves. P. Germain. N.A.C.A., T.N. 3299 (*June* 1955).

The properties of the solutions corresponding to the reflection of a centred simple wave along a straight line or along a free stream line are shown to be closely related to some important theorems predicting "*a priori* bounds" for special mathematical problems. These properties thus appear to be a physical interpretation of those theorems.—(1.2.0.1).

Control Surfaces

Two-dimensional control characteristics. L. W. Bryant et al. R. & M. 2730 (*April* 1950, *published* 1955).

Researches on the lift, pitching moments, and hinge moments of aerofoils with plain flaps have been carried out at the National Physical Laboratory at a Reynolds number of about 10^6. The results of the experiments have been presented in a generalised form, which shows promise of being applicable over a wide field. The generalised curves have been tested as far as possible from other sources, including some tests made on one of the National Physical Laboratory sections in a Royal Aircraft Establishment Tunnel at Reynolds numbers up to nearly 10^7.—(1.3.0).

Summary of results of a wind-tunnel investigation of nine related horizontal tails. J. B. Dods and B. E. Tinling. N.A.C.A., T.N. 3497 (July 1955).

Data has been compiled for models of nine related horizontal tails. The majority of the results were obtained at a Mach number of approximately 0·20. Three of the models were tested throughout the subsonic Mach number range to a maximum of 0·94. The Reynolds number range was from 2 to 4 million. The models had aspect ratios from 2 to 6, angles of sweepback from 5·7° to 45°, and had 30 per cent. chord, sealed, plain flaps. The lift coefficient, hinge moment coefficient, and pressure coefficients across the elevator nose seal are presented. The effects of sweepback, aspect ratio, and Mach number on the lift and hinge-moment parameters are summarised. Comparisons of the experimental results with theoretical calculations are presented.—(1.3.3).

NOTE.—*The figures in parenthesis at the end of each Summary are for office use only.*

Fluid Dynamics

See also Boundary Layer

The structure of turbulence in fully developed pipe flow. J. Laufer. N.A.C.A. Report 1174 (1954).

Measurements, principally with a hot wire anemometer, were made in fully developed turbulent flow in a 10-inch pipe at speeds of 10 and 100 feet per second. It is shown that rates of turbulent-energy production, dissipation, and diffusion have sharp maximums near the edge of the laminar sub-layer and that there exist a strong movement of kinetic energy away from this point and an equally strong movement of pressure energy toward it.—(1.4.2).

Internal Flow

Flight determination of the drag and pressure recovery of an N.A.C.A. 1-40-250 nose inlet at Mach numbers from 0·9 to 1·8. R. I. Sears and C. F. Merlet. N.A.C.A., T.N. 3218.

External-drag and pressure-recovery data are presented for the N.A.C.A. 1-40-250 nose inlet. The tests were made using rocket-propelled models in free flight at Mach numbers from 0·9 to 1·8. The Reynolds number based on body diameter varied from 4×10^6 to 10×10^6.—(1.5.1).

An investigation of the discharge and drag characteristics of auxiliary-air outlets discharging into a transonic stream. P. E. Dewey and A. R. Vick. N.A.C.A., T.N. 3466 (*July* 1955).

The aerodynamic characteristics of auxiliary air outlets of rectangular cross section discharging into a transonic stream have been investigated. The effects of aspect ratio, inclination, curvature, and recess depth upon the discharge coefficients have been determined for thin-plate and ducted-approach outlets. Surface pressure distributions in the vicinity of ducted outlets and vent pressures with no discharge are also presented. In addition, force coefficients have been measured for a few of the ducted-approach models.—(1.5.1).

Theoretical performance characteristics of sharp-lip inlets at subsonic speeds. E. A. Fradenburgh and DeMarquis D. Wyatt. N.A.C.A., Report 1193 (1954).

A method is presented for the estimation of the subsonic flight speed characteristics of sharp-lip inlets applicable to supersonic aircraft. The analysis, based on a simple momentum balance consideration, permits the computation of inlet pressure recovery mass flow relations and additive-drag coefficients for forward velocities from zero to the speed of sound.—(1.5.1).

Stability and Control

A criterion for the prediction of the recovery characteristics of spinning aircraft. T. H. Kerr. A.R.C., C.P. No. 195 (1955).

In an attempt to establish a simple criterion for the prediction of the spin and recovery characteristics of aircraft, it has been deduced that the two most important parameters are the unbalanced rolling moment coefficient about the wind axis in the spin and the ratio of pitching to rolling moment of inertia. Using the results of full scale spinning tests on thirty-three aircraft, it has been possible to establish empirical relationships between the estimated unbalanced rolling moment coefficient and the inertia ratio which effectively divide the aircraft into the three groups which have satisfactory, borderline and unsatisfactory recovery characteristics.—(1.8.3).

Model tests on the effects of slipstream on the flow at various tailplane positions on a four-engined aircraft. Part I. Tests with contra-rotating propellers. D. E. Hartley et al. Part II. Tests with single rotating propellers. D. A. Kirby. R. & M. 2747 (*March* 1951, *published* 1955).

Systematic wind-tunnel tests have been made to investigate the effects of slipstream on the flow near the tailplane of a typical civil transport with four contra-rotating propellers. Tailplane height has been varied for each of several wing-body arrangements; only one tailplane and one propeller position have been used. The main results are presented in the form of changes in mean downwash angle, and velocity at the tailplane, as functions of tailplane position, lift coefficient, and propeller thrust.—(1.8.2)

AIRCRAFT OPERATION

See also Aerodynamics: Wings and Aerofoils and Propellers

Summary evaluation of toothed-nozzle attachments as a jet-noise-suppression device. W. J. North. N.A.C.A., T.N. 3516 (*July* 1955).

Toothed attachments to a full-scale turbo-jet nozzle were investigated for possible jet noise reduction and thrust penalty. The attachments caused slight reductions in total sound power that are insignificant when evaluated in terms of engine thrust losses and aircraft payload penalty. At the reduced thrust levels obtained with the toothed nozzles, corresponding sound power reductions could be realised by throttling the standard turbo-jet engine. Sound pressure levels were reduced behind the engine but were increased elsewhere.—(5.1.0).

Investigation of eye movements of an aircraft pilot under blind approach conditions. A. F. A. Watts and H. C. Wiltshire. CoA College Note No. 26 (*May* 1955).

Eye movement patterns were obtained of a pilot in an aircraft fitted with a standard R.A.F. blind flying panel on several approaches under Standard Beam Approach conditions. These patterns were obtained by photographing the reflection of the pilot's eyes in a mirror attached to the instrument panel.—(5.3×9).

AIRPORTS

Determination of some geometric relationships pertaining to collision flight paths. W. D. Howell and T. M. Edwards. C.A.A. Technical Report No. 259 (*June* 1955).

A study has been made to develop a basic means, in the form of graphs and charts, for permitting a better understanding of cockpit visual problems and aircraft conspicuity problems as they are related to mid-air collisions.—(6.5).

ELECTRONICS

The development of an improved VOR/TVOR monitor. R. A. Forcier and W. H. Klein. C.A.A. Technical Development Report No. 271 (*June* 1955).

This report describes an improved VOR (or TVOR) monitor developed at the Technical Development and Evaluation Center of the Civil Aeronautics Administration, Indianapolis, Indiana. Work on the monitor was initiated at the conclusion of the TVOR development with the primary objective of producing the companion monitor required for the TVOR to attain commissioned status.—(11).

HYDRODYNAMICS

N.A.C.A. model investigations of seaplanes in waves. J. B. Parkinson. N.A.C.A., T.N. 3419 (*July* 1955).

The models, apparatus, and instrumentation developed for investigations of the rough water characteristics of seaplanes in the Langley tanks are described briefly. The results of several investigations to improve these characteristics are combined and summarised. The large effect of waves in take-off resistance is illustrated. The general relationship of the measured quantities of importance to wave length and height are also illustrated.—(17.2).

MATERIALS

The production of ductile electrolytic chromium. H. T. Greenaway. A.R.L. Report Met. 6 (*December* 1954).

The production of electrolytic chromium containing 0·01-2·02 wt. per cent. oxygen and 0·002 wt. per cent. nitrogen as its major impurities, is described together with a hydrogen reduction technique for reducing these values to below the chemically detectable amounts, *i.e.* 0·005 wt. per cent. and 0·001 wt. per cent. respectively.—(21.1).

The flexural fatigue strength of coin dimpled 75S-T aluminium alloy sheet. S. W. Gee and J. Y. Mann. A.R.L. Structures and Materials Note 215 (*December* 1954).

Flexural fatigue tests have been made on unnotched specimens and coin dimpled specimens of 75S-T aluminium

alloy sheet, the coin dimples being formed using both cold and hot dies.—(21.2.1).

Tensile properties of 7075-T6 and 2024-T3 aluminum-alloy sheet heated at uniform temperature rates under constant load. G. J. Heimerl and J. E. Inge. N.A.C.A., T.N. 3462 (*July* 1955).

Results are presented of tests to determine the effect of heating at uniform temperature rates from 0·2° to 100°F. per second on the tensile properties of 7075-T6 (75S-T6) and 2024-T3 (24S-T3) aluminium-alloy sheet under constant-load conditions. Yield and rupture stresses, obtained under rapid-heating conditions, are compared with results of elevated-temperature stress-strain tests for ½-hour exposure. Master yield and rupture stress curves based on a linear temperature rate parameter are presented.—(21.2.2).

Effect of some selected heat treatments on the operating life of cast HS-21 turbine blades. F. J. Clauss et al. N.A.C.A., T.N. 3512 (*July* 1955).

Effects of heat treatment depend upon initial microstructure of cast blades. Blades from one manufacturer performed best in the as-cast condition; blades from a second manufacturer performed best after ageing 48 hours at 1,500°F. Solution treatments at 2,050°F. and above often caused damage by eutectic melting.—(21.5).

MATHEMATICS

Extrapolation techniques applied to matrix methods in neutron diffusion problems. R. R. McCready. N.A.C.A., T.N. 3511 (*July* 1955).

An iterative scheme is developed for the matrix solution of the type of characteristic-value problem arising from homogeneous linear equations. The scheme is shown to minimise a suitable form at each step. Extrapolation techniques for speeding convergence are developed and refined. An example from nuclear-reactor theory is presented.—(22).

POWER PLANTS

Fire-extinguishment studies of the Convair-340 power plant. L. A. Asadourian. C.A.A. Technical Development Report No. 265 (*June* 1955).

Fire tests were conducted in the necessary section of a full-scale operable CV-340 nacelle in order to evaluate the extinguishing system used in this power plant. A study was made of the recommended emergency procedure in which the existing air-vent door at the top of Zone 2 is closed during extinguishment. Comparative studies were made of emergency procedures in which the vent door was left open and in which both the vent door and the air-inlet duct to the zone were closed.—(27.2.1).

Fire resistance studies of the Convair-340 power plant. L. A. Asadourian. C.A.A. Technical Development Report No. 266 (*June* 1955).

During the period that fire-detection and extinguishing tests of the CV-340 power plant were in progress, the installation was also studied with respect to its fire resistance. Air flow and leakage in the power and accessory sections were studied with the aid of a dye introduced into the air stream upwind of the nacelle under simulated flight conditions. The dye technique proved to be a practicable means of detecting loose fits between mating parts. Test fires in the nacelle revealed which materials and components are most likely to fail during a power-plant fire.—(27.2.1).

Approximate method for determining equilibrium operation of compressor component of turbojet engine. M. C. Huppert. N.A.C.A., T.N. 3517 (*July* 1955).

A method is presented for estimating the equilibrium operating line for a compressor as a component part of a turbojet engine. The results of this analysis are presented in chart form to facilitate rapid determination of the equilibrium operating line. Predicted and measured equilibrium operating conditions are compared in terms of compressor pressure ratio and equivalent weight flow; satisfactory agreement is indicated.—(27.1).

PROPELLERS

Noise survey of a 10-foot four-blade turbine-driven propeller under static conditions. M. C. Kurbjun. N.A.C.A., T.N. 3422 (*July* 1955).

Overall sound-level measurements and tape recordings of the noise emitted from a 10-foot-diameter, four-blade propeller mounted on a propeller-research vehicle have been made under static conditions at stations spaced on a 75-foot-radius circle about the propeller. The tape recordings were analysed to obtain the frequency spectra at each station and comparisons of the results are made with theory. The effects of microphone position above the ground are also given.—(29.1 × 5.0).

STRUCTURES

LOADS

Vibration characteristics of a cantilever plate with swept-back leading edge. A. E. Heiba. CoA College Report No. 82 (1954).

An experimental study of natural frequencies and modes of vibration of uniform cantilever plates is presented. Sixteen plan forms are tested by combining aspect ratios of 0·8, 1·2, 1·6 and 2 with leading edge sweepback angles of 0°, 15°, 30° and 45°. Experimental values of the natural frequencies for the first six modes are presented for each plate, together with the nodal patterns concerned. The results have been plotted in frequency curves of the same "family shape."—(33.1.1 × 33.2.4.7.0).

The influence of aeroplane characteristics on the response to gusts of various forms. F. H. Hooke. A.R.C.C. (Australia) Report ACA-54 (*August* 1954).

This work was undertaken primarily with the intention of investigating the dynamic behaviour of a flexible aeroplane when flying through an unsteady atmosphere, and of determining the changes in behaviour as the various significant aircraft parameters were altered to correspond to changes in altitude, wing loading, wing natural frequency, and so on. The report comprises two parts: Part I in which structural rigidity was assumed and Part II in which flexibility in the form of a simple wing flapping motion was added. By the choice of suitable parameters the gust disturbance and aircraft response were expressed non-dimensionally. —(33.1.2).

Static strength and fatigue properties of threaded bolts. W. Weibull. F.F.A. Meddelande 59 (1955).

The tensile strength of 497 double screw joints has been determined and its distribution has been found to be neither normal nor log-normal. An exponential distribution function previously used by the author fits the data reasonably well. The fatigue lifetimes of 417 of the same joints have been measured at five stress levels. The distributions at the lower levels consist of two components. If the upper (with regard to life) components are neglected, all the remaining data may be pooled into one distribution, the statistics of which have been computed. The statistical fatigue properties have been condensed into one single equation, the *P-S-N* equation.—(33.1.2 × 33.2.4.1.0).

Structural response to discrete and continuous gusts of an airplane having wing-bending flexibility and a correlation of calculated and flight results. J. C. Houbolt and E. E. Kordes. N.A.C.A. Report 1181 (1954).

An analysis is made of the structural response to gusts of an aeroplane having the degrees of freedom of vertical motion and wing bending flexibility. Convenient solutions of the response equations are developed for discrete and sinusoidal-gust encounter, and the procedure is given for treating the realistic condition of continuous random atmospheric turbulence. Flight and calculated results are then given for several aeroplanes to evaluate the influence of wing bending flexibility on the structural response to gusts. This report was formerly T.N. 3006.—(33.1.2).

Simplified procedures and charts for the rapid estimation of bending frequencies of rotating beams. R. T. Yntema. N.A.C.A., T.N. 3459 (*June* 1955).

A Rayleigh energy approach utilising the non-rotating beam bending modes in the determination of the bending frequencies of the rotating beam is evaluated and is found to give good practical results for helicopter blades. Charts are presented for the rapid estimation of the first three bending frequencies for rotating and non-rotating cantilever and hinged beams. A more exact mode expansion method used in evaluating the Rayleigh approach is also described. Numerous mode shapes and derivatives are presented in tabular form and discussed. This note supersedes and extends R. & M. L54G02.—(33.1.2).

On spectral analysis of runway roughness and loads developed during taxiing. J. C. Houbolt et al. N.A.C.A., T.N. 3484 (*July* 1955).

The application of the technique of generalised harmonic analysis as a means for determining aeroplane taxi-ing loads is considered in a cursory manner. Some results on runway roughness are reviewed and some results obtained from taxi-ing tests of a large aeroplane are given.—(33.1.2).

THEORY AND ANALYSIS

See also LOADS

Improvements in the fatigue strength of joints by the use of interference fits. W. A. P. Fisher and W. J. Winkworth. R. & M. 2874 (*May* 1952, *published* 1955).

A study is made of the effect of interference fits in loaded holes on the fatigue strength of the associated part. Fatigue-test results are given for aluminium alloy flat bars with a single hole loaded by a pin in double shear. Two series of tests were made. In one series the pin was fitted directly in the hole with various degrees of interference fit up to 0·003 in. excess diameter. The other series had a mild steel bush interposed with similar degrees of interference in the bar, but with a push fit between pin and bush. Both sets showed a great increase in fatigue strength for interference fits above a critical value. The application of these results for raising the fatigue strength of aircraft structural joints is considered.—(33.2.4.13.10).

An experimental investigation of stress diffusion in non-buckling plates. L. H. Mitchell. R. & M. 2878 (*May* 1952, *published* 1955).

The purpose of this report is to provide experimental results for comparison with theoretical analyses of stress diffusion problems. The structures considered consist of plane reinforced sheet which has been assumed not to buckle. Symmetrical loads are applied to the edge booms connected to the sheet by continuous no-slip joints. Attention is concentrated on the stress distribution near the ends of the parallel strips of plate. An outline of the existing theoretical work which is applicable to this type of problem is given and the stringer-sheet theory is compared with the photo-elastic results.—(33.2.4.6.8).

Determination of the stress distribution in reinforced monocoque structures. Part I. A theory of flat-sided structures. L. S. D. Morley. R. & M. 2879 (*December* 1951, *published* 1955).

This paper is concerned with the formation of basic differential equations for the determination of the stress distribution in reinforced monocoque flat-sided structures, such as rectangular or polygonal fuselages and wing boxes. The general scheme of the analysis is to develop the fundamental equations which govern the stresses, strains and displacements separately in the skin-stringer combination and rib flanges. Then, by identifying displacements along their intersections, the differential equations of compatibility are formed. The solution of these equations yields the stress distribution. A simple application of the theory is demonstrated in an appendix.—(33.2.3.1 × 33.2.3.3).

*The buckling of a clamped parallelogram plate under combined bending and compression. J. Guest. A.R.L. Report S.M.*227 (1955).

This paper deals with the buckling of a clamped parallelogram plate under combined bending and compression, four cases being studied in detail. Case 1 deals with the pure bending of a clamped plate. Case 2 treats the same plate in pure compression under a linearly varying compression applied at opposite edges. Cases 3 and 4 deal with unsymmetric stress distributions. Galerkin's variation of the Rayleigh-Ritz method has been used to find the various critical buckling stresses.—(33.2.4.5.6).

The influence of low temperature on the strength of redux bonded single lap joints of 24 *and* 75 *S-T clad. A. Hartman. N.L.L. Report M.*1973 (*December* 1954).

The principal tests carried out to determine the influence of low temperature on the shear strength of redux bonded simple lap-joints of 75 S-T or 24 S-T alclad sheet were short time tensile tests at room temperature, −20°C. and −55°C. and long time tensile tests at room temperature and −55°C. —(33.2.4.13.9).

*On the buckling problem in the plastic range for struts and plates. Part III. Experiments and non-dimensional buckling curves. J. F. Besseling. N.L.L. Report S.*444 (1955).

Results of compression tests on plates with simply-supported and free longitudinal edges are compared with the critical stresses in the plastic range according to various formulae. For all specimens the critical stresses were at the same time the ultimate values of the stress. A semi-empirical formula is recommended for engineering practice. Non-dimensional buckling curves are based upon the Ramberg-Osgood expression for the stress-strain curve.—(33.2.2).

On the mechanism of buckling of a circular cylindrical shell under axial compression. Y. Yoshimura. N.A.C.A., T.M. 1390 (*July* 1955).

The present paper deals with the buckling of a circular cylindrical shell under axial compression from the viewpoint of energy and the characteristics of deformation. It is shown first, both theoretically and experimentally, that the reason why the buckling of a cylindrical shell is quite different from that of a flat plate is attributable to the existence of a nearly developable surface far apart from the original cylindrical surface, which is equivalent to the existence of an approximately inextensional finite deformation.—(33.2.4.3.6).

Shearing effectiveness of integral stiffening. R. F. Crawford and C. Libove. N.A.C.A., T.N. 3443 (*June* 1955).

Values of coefficients for defining the effectiveness of integral stiffeners in resisting shear deformations of the plate of which they are an integral part are presented for a variety of proportions of rectangular stiffeners with circular fillets. Formulae are given in which these coefficients may be employed to calculate the elastic constants associated with the twisting and shearing of integrally stiffened plates. The size of fillet radius is shown to contribute appreciably to the degree of penetration of the stresses from the skin into the stiffener.—(33.2.4.6.4).

Tables of coefficients for the analysis of stresses about cutouts in circular semi-monocoque cylinders with flexible rings. H. G. McComb and E. F. Low. N.A.C.A., T.N. 3460 (*July* 1955).

Tables of coefficients are presented which facilitate the stress analysis of circular semi-monocoque cylinders with cut-outs by the method published in N.A.C.A. T.N. 3200. When the values of two simple structural parameters are known, use of these coefficients enables shear flows and stringer loads in the neighbourhood of a cut-out to be calculated. The effect of bending flexibility of the rings in their planes has been taken into consideration in the computation of the coefficients.—(33.2.4.3.0).

TESTING

Permissible design values and variability test factors. R. J. Atkinson. R. & M. 2877 (*July* 1950, *published* 1955).

On the basis of a fixed probability, Part I deduces: (*i*) expressions for the derivation of permissible design values from a given number of test results, (*ii*) the number of test results required, on specimens chosen at random, so that the estimates of permissible design values can be regarded as sufficiently accurate, (*iii*) the factor which should be applied to the results of tests on any number of similar components designed to meet a specified requirement. The effects of different probabilities and of different acceptable proportions of weak specimens are investigated in Part II.—(33.3.2).

THERMODYNAMICS

Effect of hydrocarbon structure on reaction processes leading to spontaneous ignition. D. E. Swarts and C. E. Frank. N.A.C.A., T.N. 3384 (*July* 1955).

The present study compares the reaction processes of other aliphatic hydrocarbons with those of the heptane and iso-octane previously studied. A study of the behaviour of olefins and some exploratory work on the effect of the ratio of surface to volume on the extent of oxidation in the early stages was also included.—(34.1.1).